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WATERS, MAGMATIC AND METEORIC.

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DEFINITIONS.

Magmatic volatile agents[1] are those contained in the liquid magma and largely separated from it during intrusion, eruption and solidification. In part they may be "resurgent," that is, absorbed by the magma during fusion of enveloped rocks (syntexis). Magmatic fluids also include primary liquid inclusions, and water bound in chemical combination in unaltered crystallized igneous rocks. Water forms the principal part of the magmatic volatile agents but they also include various other volatile compounds and solids in solution.

The meteoric volatile agents are derived: (1) From rain water precipitated on the surface and (2) from connate sources (fresh or marine waters buried with sediments and surface volcanics). Most of the water in sedimentary rocks, occluded or in chemical combination, is also of meteoric origin. Water forms the principal part, but also included are various other volatile agents and solids in solution. The active meteoric waters in the rocks are chiefly contained in their pores and openings.

Magmatic waters expelled from the magmas may also enter into the pores and openings of adjoining or superimposed rocks, or they may join the meteoric circulation.

It is probable that all the water of the earth was originally "magmatic."

[1] Daly, Reginald A.: Genetic Classification of Underground Volatile Agents. ECON. GEOL. 12, 487–504, 1917.

METEORIC WATERS.

The meteoric waters are largely contained in the atmosphere and in the seas (whatever the opinion may be as to the original source of the sea water), and they also penetrate the rocks of the crust but are necessarily confined to its uppermost part. Opinions as to origin and quantity of underground waters have varied widely, and even in recent times important swings have taken place in the views held. Van Hise thought that the amount of free water would equal a sheet 226 feet deep over the continental areas. Fuller in 1906 reduced this to a more probable estimate of 96 feet, and for some time afterwards the tendency was to minimize the volume; this was based on facts shown by mining and deep drilling. Many mines reaching a depth of from 3,000 to 7,000 feet are practically dry at the bottom; many wells in sedimentary rocks are dry down to similar depths. The term "dry" is, however, relative in a way, for although flowing water may be absent, there may be quite a considerable amount of rock moisture which evaporates rapidly from the exposed surfaces. This tendency to minimize the quantity and importance of meteoric water was perhaps most forcibly expressed by J. F. Kemp[2] in two notable and thoughtful papers.

In 1913[3] the writer expressed the opinion that "water in quantities to supply an ascending circulation can only exceptionally attain a depth of 10,000 feet, and except in regions of great dynamic movements, the active circulation is confined to the uppermost few thousand feet." This statement needs some modification.

The first thesis advanced in this paper is that although the above statement is generally true for igneous and metamorphic rocks not excessively fractured, it is not quite correct for sedimentary unaltered rocks, which commonly have a high porosity.

The second thesis advanced and strongly emphasized is that

[2] Kemp, J. F.: Igneous Rocks and Circulating Waters as Factors in Ore Deposition. Trans. Amer. Inst. Min. Eng. 33, 699–714, 1903; The Groundwaters. Trans. Amer. Inst. Min. Eng., 45, 3–25, 1914.

[3] Mineral Deposits, p. 34; also in later editions.

the present distribution and composition of the water in a body of rocks may be entirely different from that prevailing at an earlier date, say when certain ore deposits in these rocks were formed, and may in fact have changed several times since an early date. Earlier waters may have been displaced by gravity, by heat, by hydration or by other waters which found their way into the beds from exposed outcrop or from fractures.

Meteoric waters may penetrate any rock to a depth of from a few hundred to a few thousand feet, the penetration being aided by the universally present fissures and joints. But in rocks with slight porosity and no active circulation, penetration soon becomes very slow; the water becomes stagnant, and mines in such terranes become practically dry in depth. Hydration and base exchange soon increase the salinity, and the water ultimately becomes scant chloride brines, first with sodium, later with calcium predominating. Sedimentary rocks are largely porous and permeable. Sandstone, conglomerate, limestone also in part, will allow water to pass. Shales are less permeable and permit only slow water movement; they contain much water but it is firmly held and in part of connate origin. The well-known movement of water in permeable sandstone need not be further explained. Hydrostatic pressure is the main moving power. In the case of the Dakota sandstone, the water is transported several hundred miles to a maximum depth of about 2,000 feet, and during the travel attains a temperature of about 70° F.

The oil regions offer many and excellent examples of the ability of water to penetrate to great depths. The distribution is variable; some deep wells in West Virginia are practically dry [4] (Lake well, 7579 feet deep); at McDonald, Pa.,[5] salt water was struck at a depth of 6200 feet (Oriskany sandstone?) and the water rose 4,000 feet in the hole. In the Goff well no water was found below 2,307 feet. The oil sands that have been so extensively explored in the Mid-Continent and in the California oil

[4] The term "dry" is really only relative, meaning that no measurable amount of water escapes from the beds. Few, if any, of these sedimentary beds are dry in a chemical sense.

[5] Reeves, Frank: ECON. GEOL., 12, 367, 1927.

regions are the main water-carriers. After the oil stops flowing the salt "edge water" comes in under varying pressure from the main reservoir of the "sand." There may be a dozen oil and water sands in a given well. Of late years much deep drilling has been done in Oklahoma and California to depths exceeding 7,000 feet. At the present writing (July, 1934) the deepest well seems to be that at Belridge, Calif., which is still drilling in Monterey shale at 11,192 feet. A deep well in Vera Cruz, Mexico, recently attained 10,000 feet in spite of high water pressure. From many of these deepest wells exact data regarding temperature and water are still lacking. Van Orstrand[6] estimates the temperature in the Pennsylvania and West Virginia field at 10,000 feet at about 200° F.; and about 220° to 290° F. in Oklahoma and California. Water in large amounts and generally saline is contained in permeable beds certainly to a depth of 8,000 feet and probably beyond 10,000 feet. In the Santa Fe Springs district (Los Angeles)[7] a well produced oil and much water from the second Clark zone at a depth of 8,000 feet, the temperature of the water being 206° F. at 7,802 feet. These sandy beds carrying salt water are of course not confined to oil regions but they have there received most attention. The salinity varies widely; the waters often contain much H_2S, sometimes also CO_2, but are generally poor in sulphates and silica. The origin of the salinity has been widely discussed. The prevailing opinion among geologists seems to be that the waters are connate, but this is probably only partly correct.

In the Sunset-Midway field, California, there are about a dozen water-bearing beds in the Etchegoin formation (Pliocene), over-

[6] Van Orstrand, C. E.: On the Nature of Isogeothermal Surfaces. Amer. Jour. Sci. (5) 15, 494–519, 1928; Temperature in World's Deepest Wells. Oil and Gas Journal, Apr. 19, 1928.

Miser: H. D.: Temperature of Oklahoma's Deepest Well. Bull. Amer. Assoc. Petr. Geol., 8, 525–536, 1924. (166° F. at 5200 feet).

Carlson, A.: Geothermal Variation in Coalinga Wells, Calif. Bull. Amer. Assoc. Petr. Geol., 15, 829–836, 1931; Geothermal Variations in the Oil Fields of the Los Angeles Basin. Bull. Amer. Assoc. Petr. Geol., 14, 997–1011, 1930. (Maximum 130° F. at 3000 feet.)

[7] W. H. Emmons, Geology of Petroleum, pp. 553–564, 1931.

lying the Maricopa (Monterey) Miocene shales. From their outcrop these beds may be followed to a depth of 3,000 to 4,000 feet and a distance of several miles. It is stated that the water pressure at the wells corresponds to the hydrostatic head and varies with the seasons. In 1920 Pack[8] wrote as follows:

> According to the views of the writer, the deeper waters are not by any means to be considered as truly connate waters—that is, the waters in which the sediments comprising the bed were laid down, still retaining the same chemical character as they had at the time of deposition. For it is evidently quite unreasonable to believe that these waters have remained quietly in the beds, retaining unchanged their original character, while other fluids such as petroleum have entered the beds and filled completely the pore spaces in some of them.

And G. S. Rogers[9] wrote in 1919:

> The very salty waters belonging to the 'brine' type occur only in the Midway Syncline or in localities where the circulation is restricted. . . . Uplift causes circulation, and meteoric waters enter the beds, diluting and forcing out the sea water.

Compaction, active from the first, tends continually to force out some of the connate water, and various agencies tend to increase the salinity. The meteoric waters entering the sands are continually changed by many complex reactions between water, oil, gas and rock, resulting in reduction of sulphates and adsorption of bases or base exchange; rarely, however, diminishing the chlorine radicle. It is a difficult task to trace these reactions.

An interesting light is thrown on the problem of the connate waters in a paper by D. K. Weaver[10] on the Santa Fe Springs district, Los Angeles. There are here at least 11 oil-bearing horizons with salt edge-waters. Measured from the top of the anticline, the Foix sand lies at a depth of 3,450 feet, the Meyer

[8] Pack, R. W.: The Sunset-Midway Oil Field, California. U. S. Geol. Survey, Prof. Paper 116, Pt. 1, 1920.

[9] U. S. Geol. Survey Prof. Paper 117, Pt. 2, p. 64, 1919.

[10] Weaver: D. K.: Encroachment of Edge-water at Santa Fe Springs. Petroleum Division. Petroleum Development and Technology, Amer. Inst. Min. & Met. Eng., 1931.

sand at 3,850 feet, and far below this the third Clark sand at over 8,000 feet. The heads (bottom pressure) of the various zones as well as the salinities of the waters are noted in the following table.

Zone	Maximum Thickness, Feet	Salinity, Grains per Gallon	Heads of Various Waters, Feet
Foix—Depth 3,450 ft.	180	170–220	Fairly low, about 1800
Bell—Depth 3,650 ft.	380	270–350	Low, 1800–1900
Meyer—Depth 3,850 ft.	700	450–700 (Av. 625)	Low, 3400–3800
Nordstrom	525	600–700	Low
Upper Buckbee	150	875	Low
Lower Buckbee	150	1050–1175	High, 500–surface
Upper O'Connell	175	1350–1500	Low, 4500–4000
Middle O'Connell	150	1400–1500	Low
Lower O'Connell	450	1500–1700	High, 800–surface
Upper Clark	150	1550	Low, 5000
Lower Clark or Hathaway—Depth over 8,000 ft.	500	1350–1550	Low, 6000

The " heads " or bottom pressures [11] measured after the cessation of oil flow do not necessarily mean hydrostatic heads because they may be influenced by remaining gas or oil pressures, but they certainly seem to indicate that some of the zones have direct connection with the surface. In some the hydrostatic head may be diminished by devious and irregular connections feeding water to the beds.

The salinity of the edge waters in the various zones increases gradually in depth from about 2,914 parts per million (170 grains per gallon) to a maximum of 29,135 parts per million. None of it reaches the salinity of sea water (36,000 parts per million), and it seems clear that if any of the water is of connate origin it must have been very materially sweetened by surface waters.

[11] Millikan: C. V.: Geological Application of Bottom Hole Pressures. Bull. Amer. Assoc. Petr. Geol., 16, pp. 891–906, 1932.

Considering the natural gradual increase of salinity in meteoric descending waters it appears that only a small part of the edge waters can be of connate origin.

Similar conditions may be found in the Mid-Continent field in much older but still relatively unaltered rocks. The Wilcox sand for instance (Ordovician) outcrops in the Arbuckle Mountains, and in several oil fields to the north this sand yields large volumes of edge water.

Saline waters of surface origin, it seems certain, may penetrate to great depths and may there attain temperatures of 160° to 200° F. They are often rich in H_2S, and it would seem that they are capable of producing ore deposits if the metals are present.

In the Appalachian geosyncline in Pennsylvania and West Virginia the water conditions have been studied with much care by Mills and Wells.[12] They say that here the distribution of gas, oil and water is due to complex events and affected by rock movements, displacement of water by oil and gas, by compaction and cementation and by evaporation into moving and expanding gases. The typical Appalachian oil-field brines are limited to those beds in which excessive influx of surface water has been prevented. Thus, these authors consider the brines in this field as connate. The salinity, chiefly NaCl, here reaches a maximum of 264,000 parts per million, although generally less than 150,000. For this field, the conclusions of the authors would seem to be justified.

It should be emphasized that all the factors involved work in the direction of salinity increasing in depth, so that if water contains less than 30,000 parts per million it would seem most likely that there has been a considerable admixture of surface water.

It is not possible to condense in this paper the voluminous discussions on oil brines; only a few of the more salient points are noted. This paper is not written for petroleum geologists but rather for the fraternity that deals with ore deposits.

[12] Mills, R. Van A., and Wells, R. C.: The Evaporation and Concentration of Water Associated with Petroleum and Natural Gas. U. S. Geol. Survey, Bull. 693, pp. 104, 1919.

MAGMATIC WATERS.

Most geologists admit that water and condensing gases given off by magmas, particularly by intrusive magmas, are an important and sometimes the only agency producing ore deposits. If the magma was intruded in rocks containing little or no water, as for instance in a large mass of older, granular, deeply buried rocks, the resulting ore deposits would probably be of wholly magmatic origin. Many intrusions with their aureole of deposits were generated at a depth that would wholly preclude the presence of meteoric waters.[13]

And still, for many thousands of feet and even for miles from the intrusion are found deposits that bear witness to deposition by liquids,—under the circumstances evidently magmatic liquids. It may be recalled that in 1924 Day, Allen and Morey,[14] of the Geophysical Laboratory, stated that the vapor pressure of water in the magma would be so reduced that "a pressure sufficient to condense the water would serve only to drive the water vapor into the magma. In other words, if water is to leave the magma at all it must do so as steam." This is equivalent to saying that the condensing emanations have no ascending power and that in order to reach regions nearer to the surface they must rely on strongly ascending currents of meteoric waters. And in a vast number of cases these artesian currents are lacking at the depths in which the intrusions take place. I do not pretend to solve this problem, but the observed facts seem to show that there is something wrong about the premises of the physicists.[15]

If, however, the intrusions reach higher levels and sedimentary rocks containing meteoric waters, whether connate or of the

[13] Many geologists believe that some intrusions take place very slowly, and in fact after beginning crystallization, and that this slow movement may extend over long time, with continuous separation of magmatic water. According to this view these hot waters may gradually penetrate overlying rocks and in them produce widespread granitization, metamorphism, and probably also metallization, much more far-reaching than the ordinary contact metamorphism.

[14] Day, A. L., Allen, E. T., and Morey, G. W.: Jour. Geol. 32, pp. 177–190, 291–295, 1924.

[15] Lindgren, W.: Hot Springs and Magmatic Emanations. ECON. GEOL., 22, 189–192, 1927.

present cycle, the proximity to the intrusion will heat the rocks, the water will begin to move, and the emanation, cooled and moving more slowly, will undoubtedly mingle with the waters and any other volatiles present, *e.g.*, carbon dioxide from limestone in process of silicification.

It is to the great credit of the men referred to above to have shown that many hot springs in volcanic regions are really largely meteoric waters of the upper circulation mingled with igneous emanations; thus, for instance, at Lassen Peak, the Sonoma Geysers, and in the thermal district of the Yellowstone. But the arguments would appear to fail in the case of mineral deposits formed at depths below the meteoric circulation.

There is probably a fair agreement among geologists that the preponderating amount of metals in ore deposits is carried up from magmatic sources; yet it must not be forgotten that meteoric waters also supply some metals and other elements which may be destined to play quite an important part in ore deposition.

The "Telemagmatic" Lead-Zinc Deposits. It has been shown above that the edge-waters in oil fields may descend to a depth of 10,000 feet and probably more; that they are moving in some kind of slow circulation; and that their temperatures may reach or exceed the boiling point; also, that they contain chlorides, hydrogen sulphide, carbon dioxide and other constituents, this probably making them capable of depositing ores if heavy metals are present. We may also recall that Siebenthal[16] has shown convincingly that there is a water circulation in the Paleozoic beds of the Ozark dome that originated since the post-Pennsylvanian uplift and following erosion. From the exposed heads of the strata the waters moved downward and outward (p. 33).

The depositing waters were in part chloride waters with H_2S, in part alkaline-earthy carbonate waters, the latter generally containing H_2S or CO_2 or both (p. 154). Near the surface, escape of CO_2 causes precipitation of lead and zinc sulphides by the H_2S remaining in the water. Many wells and springs deposit a

[16] Siebenthal, C. E.: Zinc and Lead Deposits of the Joplin Region, Mo., Kans., and Okla. U. S. Geol. Survey, Bull. 606, 1915.

mud containing Pb, Zn, and Cu (see particularly the Sulphur Spring of Arkansas, p. 185) besides quartz crystals, calcite and much pyrite. These waters show predominating chloride salinity. Siebenthal recognizes the continual change in composition of the waters during geological periods. Finding that zinc is present in many waters and their deposits, he concluded that the metals were dissolved from the limestones of the early Paleozoic period and transported to the present deposits. He fortified this plausible theory with calculations showing that the quantities of metals involved were quite within the possible limits.

In the last two years two important papers have been published by W. H. Newhouse.[17] In the first he shows that fluid inclusions are abundant in the galena of various regions where lead-zinc deposits occur, particularly in the Mississippi Valley region, and that these inclusions contain a highly concentrated solution of sodium and (less) calcium chloride. A small amount of H_2S and CO_2 may be present. The salinity is estimated at 12 to 25 parts per 100 grams of water. In the second paper, he showed how, by means of the disappearing of the bubble in inclusions in sphalerite in the same districts and region, the temperatures of formation could be closely approximated. He obtained for Joplin sphalerite 125° to 135° C. and for the Wisconsin deposits 80° to 105° C., and generally higher figures from various European occurrences. He pointed out that the concentration of the salts was much greater than that in the circulating water to which Siebenthal assigned a genetic rôle. Newhouse observed that many of the edge-waters of petroleum sands have a composition similar to these inclusions but, on the other hand, thinks that no sustained circulation could be maintained by these local saline waters. His conclusion is that the waters were ascending and of magmatic origin.

Siebenthal showed that many waters in the Mississippi Valley region contain zinc and iron with less lead and copper, and that

[17] Newhouse, W. H.: The Composition of Vein Solutions as Shown by Liquid Inclusions in Minerals. ECON. GEOL., 27, 419–436, 1932; The Temperature of Formation of the Mississippi Valley Lead-Zinc Deposits. ECON. GEOL., 28, 744–750, 1933.

those waters are usually only moderately saline,[18] a few indeed of secondary alkalinity; and further, that the metals mentioned are found in many reservoir sediments, as well as in the deposit of the Arkansas sulphur springs (p. 185). Certainly zinc is widely distributed in waters of which magmatic origin is very far from being proved, and in small quantities the sulphide is found widely disseminated with limestones. But the important deposits are equally certainly concentrated in circumscribed regions and localities, e.g. the Tri-State district, southeastern Missouri, and Wisconsin, and they are here concentrated in such volumes as to seriously shake the confidence of geologists in the meteoric waters as their source. Nor are the zinc-lead deposits closely associated with the saline edge-waters. For a substantiation of this we may point to the absence of these metals in the Pennsylvania geosyncline, in the salt waters of the Oklahoma oil fields, and in the oil fields of California. It is true that bitumens and oil occur in some of the Oklahoma deposits in the Picher zinc-lead field, but the association seems more or less accidental.

All this seems to point to a separate introduction of zinc and lead from magmatic sources, perhaps at the close of the Cretaceous igneous activity of the region. No doubt such magmatic waters would be liberally mixed with waters contained in the sedimentary rocks. Questions not yet satisfactorily answered relate to the general absence of other elements commonly associated with magmatic waters (except a little silver and trace of arsenic); to the tenacious holding of the lead and zinc until nearing the surface, usually below impervious covers; to the low temperature of deposition; and to the type of intrusions yielding the magmatic products. On the other hand, the waters contained and deposited much silica, a substance generally absent in the meteoric waters of high primary salinity.

So there are still many doubtful points to consider. Looking abroad for a moment, there are parallel cases in other zinc-lead regions such as the Belgian field and the Silesian region,—both in sedimentary rocks permeable to meteoric waters, both showing

[18] U. S. Geol. Surv., Bull. 606, pp. 150, 164 and 185.

large and rich deposits, and both indicating near-surface deposition at low temperatures.

If these "telemagmatic" deposits really are of partly magmatic origin, as now seems likely, they would seem to be most closely connected with the epithermal deposits.

The Witwatersrand.—In this celebrated district there are two opposing opinions as to origin. There are those (probably the most numerous) who advocate a placer origin of the deposits, and those who believe that the gold was introduced into the conglomerates by magmatic waters; among the latter, Professor L. C. Graton is the most recent proponent. The present writer is content to leave the discussion to those who have a first-hand knowledge; just a few words about present and past conditions. From the mines in the upper part of the Witwatersrand system the town and the mills draw practically all the water needed. Thus, that part of the beds would appear to be permeable. From all accounts the water is not markedly saline; much less so than would be expected. Regarding the deepest workings at or below 7000 feet, it is, curiously enough, difficult to obtain reliable information owing to the fact that they must be kept wet to prevent dust. Some authors say that these workings are dry when opened. But what were the conditions just after the folding and uplift of the beds when, according to the ascensionists, the auriferous deposits were formed? Were not the beds then easily permeable with an active circulation of the water? Of course that was a long time ago, and little is known about the physiography and the paths of the water at that time, before the beds had been cemented. They most likely were far more permeable than now, and there is a strong probability that any ascending magmatic water would find considerable meteoric water to mix with. At any rate, if it is admitted for the sake of argument that the beds are now dry at 7000 feet, it certainly does not follow that similar conditions existed when the metallization (if nonplacer) was effected. The whole question seems to the writer to be still open.

The Lake Superior Copper Deposits.—A purely magmatic ori-

gin of the depositing waters is earnestly advocated with much ability by Butler, Burbank, Graton and Broderick, the authors of Professional Paper 144 of the U. S. Geological Survey. The waters originated from the magma of the intrusive Duluth gabbro, followed the porous "tops" of the volcanic flows or along the porous felsitic conglomerates for a long distance, probably 20,000 to 40,000 feet, and deposited the copper underneath the impermeable barrier of the next overlying flow. Along a distance of 65 miles, or 300 miles if we assume that the copper belt continues into Wisconsin and Minnesota, the magmatic waters ascended in enormous volume, depositing copper and forming large amounts of calcium-magnesium-aluminum silicates. These three metals can not be considered to be magmatic emanations but were clearly taken up by the waters during their long ascent along the lava flows.

The present water conditions are beyond dispute. There is meteoric fresh water in the rocks down to about 1500 feet; from there on, the waters became more saline and at 5000 feet there are only feeble drips of highly concentrated solutions of sodium and calcium chlorides.

Now let us consider the history in more detail. A pre-Keweenawan erosion planed off the earlier rocks, and in the middle Keweenawan a series of basaltic flows accumulated to a maximum thickness of 30,000 feet. This pile was probably surrounded by continental deposits; some think that saline lakes were present; at any rate, it can hardly be assumed that it was wholly dry. After the eruption cooled a thick series of sandstones and conglomerates were laid down over them. The general opinion seems to be that these were continental, but the presence of precipitation and water penetrating the beds, perhaps to great depth, can scarcely be denied. Then followed folding, bringing the series into its present position; the Keweenawan faults and overthrusts were beginning to form. From the exposed heads of the strata, water again advanced downward, no doubt becoming salty in depth.

Then followed the intrusion of the Duluth gabbro and the

main mineralization of lava beds and fault. The copper deposits were formed. A long epoch of denudation reduced the Keweenawan to a peneplane; the Cambrian Sea advanced, covering the heads of the strata, and no doubt the salt water penetrated in places to great depth. The great Keweenawan overthrust was still working and finally separated the Cambrian sediments from the older rocks.

It is not probable that anyone is capable of concluding with certainty what the water conditions were in the Keweenawan preceding the intrusion of the gabbro. To clarify the matter further it may be well to add that no positive evidence has been adduced that the intrusive gabbro really exists in the continuation of the lava flow downwards. The past history of the ground water in this region is certainly not ascertained beyond doubt. Thus, although definite conclusions have not been established, enough has been said to convince geologists that the story of underground waters in past periods is neither simple nor easily read.

SUMMARY.

After some definitions, the quantity and distribution of the meteoric waters is discussed. The present tendency to minimize their quantity and importance has perhaps gone too far. The thesis is advanced that meteoric waters in permeable sedimentary rocks may easily reach a depth of 8,000 and possibly over 10,000 feet. Examples are taken from the oil fields of various regions. The salinity tends to increase, owing to several factors, but in relatively few places are these waters to be considered wholly of connate origin. In igneous and metamorphic rocks the cementation generally prevents any active penetration by surface waters except to depths of about 3,000 feet at most. The second thesis advanced (for which no originality is claimed) is that the present distribution and composition of the water in a body of rock may be entirely different from that prevailing at an earlier date (say when certain ore deposits now contained in them were formed) and may in fact have changed several times since an early date.

Magmatic waters are then discussed and are considered as a principal agency in the formation of mineral deposits. In the case of deep-seated intrusion below the limit of moving meteoric waters, the deposits surrounding them are no doubt wholly of magmatic origin.

Hot springs are generally a mixture of meteoric waters and magmatic emanations. But the idea sometimes advanced that magmatic emanations cannot ascend once they have been expelled from the source, except when carried upward by currents of the meteoric circulation, is strongly opposed.

The " telemagmatic " lead-zinc deposits of the Mississippi Valley and other districts in Europe are examined and the conclusion reached that they are formed by mixtures of magmatic and meteoric waters, generally saline, and that they were formed as shown by Newhouse at comparatively low temperatures, and that they are most closely related to the epithermal deposits. Some of the difficulties and objections in respect to this view are enumerated.

Finally, the deep waters in past periods in the Witwatersrand district are briefly considered. A more detailed analysis is made of the events prevailing during the Keweenawan in the region now occupied by the Lake Superior copper deposits, and the conclusion is reached that many and important changes in the water conditions have taken place. The opinion is advanced that during the deposition both magmatic and meteoric waters were present.

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ROCK ALTERATION AT THE AMULET MINE, NORANDA DISTRICT, QUEBEC.[1]

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THE ore deposits of the Amulet mine are of interest, partly because of the manner in which they illustrate the close relationships of ore deposits to the character and structure of the enclosing rock, and partly because of the unusual type of rock alteration associated with them. They lie about 5 miles northwest of Noranda and, except for the presence of considerably less gold and much more sphalerite, are essentially similar in mineralogical composition to the ore masses at the Noranda mine. Although there is little doubt that the ore of the Amulet and the Noranda was derived from the same source, the difference in the proportions of the minerals present in the two localities and the absence, so far as known, of the peculiar cordierite-bearing alteration rock, dalmatianite, at the Noranda suggest that the composition of the emanations from which the ore was deposited and the conditions of deposition were somewhat different at the two properties.

The principal geological descriptions of the Amulet mine, so far published, are those of J. G. MacGregor [2] and H. C. Cooke.[3] In these are described the occurrence of most of the ore deposits in rhyolite flow breccia beneath its contact with andesite, and the association of the dalmatianite with the ore deposits, relationships first noted by Mr. MacGregor. The mineralogical descriptions

[1] Published with the permission of the Director, Geological Survey of Canada, Department of Mines, Ottawa.

[2] MacGregor, J. G.: Structural Features of Certain Rouyn Orebodies. Can. Min. Jour., vol. 49, pp. 456–460, 1928; Exploration in Rouyn Camp. Trans. Can. Inst. Min. and Met., vol. 32, pp. 41–50, 1929.

[3] Cooke, H. C.: The Amulet Mine, Quebec. Trans. Can. Inst. Min. and Met., vol. 33, pp. 398–408, 1930; Geology and Ore Deposits of the Rouyn-Harricanaw Region. Quebec Geol. Surv. Can., Mem. 166, pp. 206–218, 1931.

and analyses of the dalmatianite contained in the paper on that rock by T. L. Walker[4] are also important contributions to the geology of the Amulet.

The following description of rock alteration at the Amulet is part of the results of a study of the property by the writer in 1931. This included the preparation of an outcrop map of an area of about one square mile adjoining the ore deposits on the scale of 100 feet to 1 inch.

GEOLOGY.

The rocks of the region in which the Amulet occurs lie almost in the middle of the Timiskaming geosyncline and, except for some quartz diabase dikes of late pre-Cambrian (probably for the most part Keweenawan) age, all belong to an early pre-Cambrian (Archean) complex of volcanics and sediments cut by numerous intrusives of various ages. The volcanics and sediments are usually divided into two groups (1) the Abitibi or Keewatin and (2) the Timiskaming, the first consisting predominantly of lava flows and volcanic ejectmenta and the second of conglomerate, graywacke and other sediments. The intrusive rocks of the complex consist of masses, dikes, or sills of andesite, dacite, and rhyolite, too small to be shown on maps of ordinary scale; masses, dikes, or sills of diorite or quartz diorite; and dikes, stocks, or batholiths of granodiorite and related acidic rocks.

The rocks occurring in the vicinity of the ore deposits of the Amulet, with the possible exception of a single outcrop of chert, are all of igneous origin. The approximate succession is as follows:

[4] Walker, T. L.: Dalmatianite, the Spotted Greenstone from the Amulet Mine, Noranda, Quebec. Univ. of Toronto Studies, Geol. Ser. 29. Univ. of Toronto Press, 1930.

Late Pre-Cambrian	(14)	Quartz diabase dike
Early Pre-Cambrian	(13)*	Dalmatianite in irregular, poorly defined masses, associated with but chiefly below ore deposits
	(12)*	Granodiorite in dikes, and a stock
	(11)*	Albite (alaskite) granite in small masses or dikes
	(10)*	Andesite dikes
	(9)*	Dacite (feldspar) porphyry dikes
	(8)	Diorite and quartz diorite in masses, dikes or sills
	(7)	Rusty-weathering, pyritic, epidotized dike rock
	(6)	Andesite dikes or sills
	(5)	Rhyolite (quartz-albite) porphyry in small masses, dikes or sills
	(4)	Andesite dikes and sills
	(3)*	Hornblende dacite (quartz-feldspar) porphyry mass
	(2)*	Quartz diabase masses or dikes
	(1)	Abitibi (Keewatin) chert, andesite, rhyolite, and rhyolite flow breccia

The similarity in composition of the above succession of intrusives to the various phases of the Abitibi volcanics as shown by their mineralogical compositions and by chemical analyses,[5] where these have been made, indicates that the entire complex belongs to a single petrographic province, characterized by a preponderance of soda over potash.

The Abitibi volcanics at the Amulet mine, although not closely folded as at the Noranda, have been considerably deformed, as shown by the numerous fractures and faults that intersect them, by their dips, which range from 20 to 45 degrees, as determined by diamond drill cores through the andesite to the rhyolite breccia contact, and by the attitudes of the flattened bottoms of pillows

* The relationships to one another of the rocks designated by numbers 9 to 13 and 2 to 3 have not yet been determined.

[5] Cooke, H. C., James, W. F., and Mawdsley, J. B.: Geol. Surv. of Can., Mem. 166, pp. 123, 125. See also Hawley, J. E.: Ann. Rept. Bur. of Mines, Que., 1930, Pt. C, p. 24.

in the andesite. They occur structurally in a series of approximately easterly trending anticlines and synclines that pitch eastward at an angle of 20 to 25 degrees and form parts of a large anticlinorium. That the lavas have also been fractured is indicated by the numerous fractures intersecting them seen both at the surface and in diamond-drill cores, notably in the vicinity of the ore deposits, and by the numerous dikes, all of which occupy fractures. The presence of faults is shown by the displacement of dikes along younger dikes, and by the slickensided surfaces of fractures in drill cores and in the mine workings. It is noteworthy that in parts of the Noranda region there is much evidence to show that the greater part of this folding and related deformation took place before the intrusion of the diorite and quartz diorite. It is probable, therefore, that mountain building was in progress in the region shortly after, if not at the time the lavas were extruded.

THE ORE DEPOSITS.

The ore deposits of the Amulet occur in five groups, three of which are extensive. Four of the groups, numbers 1, 3, 4, and 5, occur in the rhyolite breccia close to its contact with the overlying andesite; the fifth, number 2, is in the andesite at a point about one-half mile east of and 1,000 feet structurally above the rhyolite breccia-andesite contact. They are all associated with and lie chiefly above masses of the cordierite-bearing alteration rock, dalmatianite. The ore masses are, for the most part, tabular in form, the highest grade ore in the case of deposits associated with the rhyolite breccia-andesite contact, lying directly beneath the andesite cover.

The ore consists chiefly of pyrite, pyrrhotite, sphalerite, chalcopyrite, granular quartz, the various minerals of the dalmatianite, and very small proportions of arsenopyrite,[6] tetrahedrite,[6] and calcite. A spectrographic analysis of the ore by M. H. Haycock, of the Ore Testing Laboratories, Mines Branch, Can., shows that the pyrite and arsenopyrite carry gold, and the chalcopyrite

[6] Identified by M. H. Haycock.

and galena carry silver. The tetrahedrite, because of the small size of its particles, was not tested spectrographically but it is almost certain that it also is silver-bearing.

The paragenesis of the ore minerals as seen in thin sections and polished surfaces, was for the most part, approximately the following order: pyrite, arsenopyrite, pyrrhotite, sphalerite, chalcopyrite, tetrahedrite and galena; but there are certain exceptions,

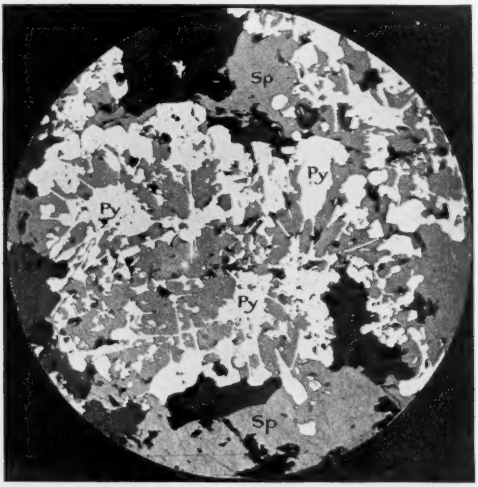

FIG. 1. Linear and cross-like areas of pyrite (*Py*) in sphalerite (*Sp*). Photograph by M. H. Haycock. × 125.

or possible exceptions to this succession. The pyrite occurs chiefly in well formed crystals enclosed in the other minerals, and in such cases was undoubtedly formed first, but in some specimens there is an interpenetration of pyrite and sphalerite and inclusions of pyrite in sphalerite. The cross-like inclusions of pyrite in sphalerite (Fig. 1), also suggest that the pyrite may be later than the sphalerite. It is possible, however, that the crosses are remnants of older pyrite that have survived replacement along crys-

tallographic lines. The presence of the pyrrhotite as inclusions with corroded margins in the sphalerite and chalcopyrite indicates that the pyrrhotite is older than both these minerals, whereas the occurrence of fine veinlets of pyrrhotite in the chalcopyrite shows that a little pyrrhotite was formed subsequent to or simultaneously with the crystallization of the chalcopyrite. The relationships of the chalcopyrite and sphalerite are not so apparent. In some places, in the polished surfaces of the ore, the chalcopyrite appears to fill fractures in the sphalerite, and its occurrence in zones following the crystal structure of the sphalerite may also indicate a later age. On the other hand, in some specimens definite branching veinlets of sphalerite cut the chalcopyrite. It is probable, therefore, that the sphalerite and chalcopyrite were deposited almost simultaneously, but in variable order of precedence at different points in the ore masses. The relationships of the ore minerals indicate, in general, that they were all deposited as part of a single deposition of ore, that the gold-bearing minerals, pyrite and arsenopyrite, were deposited first and the silver-bearing minerals, chalcopyrite, tetrahedrite, and galena, with the sphalerite, were deposited last.

It is noteworthy that, on weathered surfaces, the matrix of the rhyolite breccia, in places where it has been partly altered to dalmatianite, consists of ridges of rhyolite enclosing depressions underlain by dalmatianite. This structure of the rhyolite strikingly resembles that of a coarsely cavernous scoriaceous lava, and suggests that the openings of the breccia matrix through which the ore-bearing emanations could easily permeate were an important factor in the replacement of the rhyolite both by ore and dalmatianite. In like manner the occurrence of breccia in the andesite adjacent to the number 2 group of deposits suggests that the open structure of the breccia was a factor in ore deposition in this locality.

DALMATIANITE.

The most unique feature of the Amulet mine is the presence in the property of the cordierite-bearing alteration rock, dalmatianite. This rock, so named by prospectors because of the

spotted appearance of its weathered surface suggesting the spots of a coach or Dalmatian dog, occurs practically everywhere in association with the ore deposits or in the rhyolite breccia to the west of, and hence structurally below, the ore masses. This relationship is also demonstrated by the diamond-drill cores, in nearly all of which the dalmatianite occurs in association with the ore but largely below it.

Lithological Character.—On its freshly broken surface the dalmatianite is a fine-grained dark gray, brownish or greenish gray rock, the color varying according to the mineral predominating in its different phases. The cordierite in some phases is indistinguishable, whereas in others it has a glossy appearance strikingly different from the dull-looking matrix. In some specimens, small rosettes of gedrite, the aluminous variety of anthophyllite, and in others, small black octahedra that proved under the microscope to be green spinel, are common. The dalmatianite, also, generally contains varying proportions of the common ore minerals pyrite, pyrrhotite, sphalerite and chalcopyrite.

On its weathered surface, the dalmatianite is characterized by numerous small protuberances. This wart-like appearance of the rock arises from the resistance to weathering of the round to bean-shaped, less commonly rectangular-shaped crystals of cordierite (Fig. 2). In some places the weathered surface also exhibits small, round, pea-like protuberances of granular quartz that, as Dr. Walker suggests, are almost certainly amygdules. On the surface of diamond drill cores the dalmatianite, as a rule, also presents a variegated appearance, and many original structures of the lava,—amygdules, breccia, and flow lamination (Fig. 3),—can be observed. Under the microscope the dalmatianite is seen to consist chiefly of two or more of the following minerals; cordierite, mica, gedrite, quartz, spinel, chlorite, magnetite, and one or more of the ore minerals pyrite, pyrrhotite, sphalerite and chalcopyrite.

The cordierite is a colorless mineral most closely resembling quartz in sections where it is unaltered. It contains so many inclusions, however, and is so commonly partly altered to the

lamellar phase or to chlorite, that large continuous areas of the fresh mineral are uncommon. In many sections the cordierite

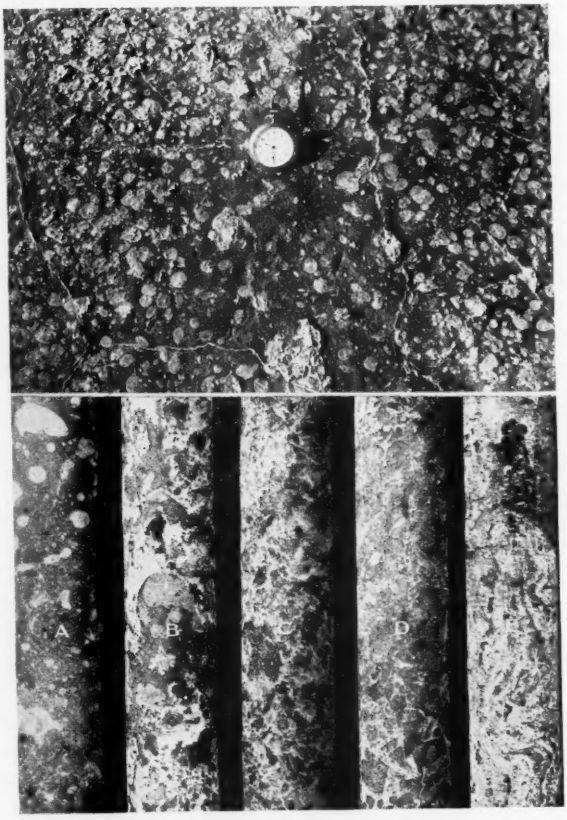

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FIG. 2 (above). Weathered surface of dalmatianite.

FIG. 3 (below). Dalmatianite in diamond-drill core. *A*, amygdules; *B* and *C*, mottled and variegated phases; *D*, breccia; *E*, flow lamination.

is twinned in irregular zones or areas and in some the six-sector (pseudo-hexagonal) twinning characteristic of cordierite was

noted. A sample of the cordierite separated for analysis was sent by T. L. Walker to H. E. Merwin of the Geophysical Laboratory at Washington for optical examination. The determinations made by Dr. Merwin were as follows: Refractive index, 1.540 to 1.550; birefringence, 010, 2 V large, optically negative. A. N. Winchell, of the University of Wisconsin, found the optical properties of another specimen of the cordierite submitted to him by H. C. Cooke,[7] to be as follows: 2 V 84°–85°; Ng. = 1.5582 (in sodium light), Mn. 1.5524, Np. = 1.5458.

The mica of the dalmatianite is a pale yellow to deep brown variety that occurs in aggregates or large areas of small and, in some sections, minute crystals of approximately uniform size. In a few thin sections the mica constitutes a large part of the rock but in many others it is entirely absent.

The anthophyllite (gedrite) is a colorless mineral with parallel extinction occurring in rosettes, sheafs and aggregates of slender fibers. The rosettes in some phases of the rock are perfectly developed. They vary in size up to a diameter of half an inch. A spectrographic analysis of the anthophyllite by Dr. Haycock showed it to contain considerable alumina, a possibility suggested by the large proportion of alumina present in the dalmatianite, as shown by chemical analysis.

The quartz of the dalmatianite is all finely granular. It occurs partly in sharply defined round, elliptical or elongated areas similar in every respect to the amygdules of the unaltered volcanics, and partly in irregular zones and aggregates. In some of the border phases of the dalmatianite there are scattered grains and aggregates of quartz, in some cases associated with feldspar, that are obviously the original quartz of the volcanic from which the dalmatianite was formed. The proportion of granular quartz in the dalmatianite is exceedingly variable. In many sections it is entirely absent or present in very subordinate amounts but in others it forms at least 75 per cent of the rock.

Spinel is a common and abundant mineral in the dalmatianite. It has a moderately deep green color and well developed cleavage, and occurs in well formed crystals, chiefly octahedra.

[7] Geol. Survey of Canada, Mem. 166, p. 215, 1931.

The chlorite is pale green, lamellar, and opaque to deep brown under crossed nicols; it occurs in irregular zones traversing the cordierite, its relationships indicating that it is an alteration product. In many thin sections of the dalmatianite a black opaque mineral occurs abundantly, partly in octahedral grains, partly in skeletal areas, and partly in parallel rodlike aggregates, that is at least in part magnetite. The presence of titanium in the rock suggests, however, that either the magnetite is titaniferous or some ilmenite is also present. In a few thin sections of the dalmatianite associated with the andesite, felty areas of partly altered plagioclase enclosed in a matrix of fine brown mica were observed. This plagioclase is similar to that of the andesite and is almost certainly a remnant of the original rock. Epidote was observed in only one thin section. It occurs in association with the cordierite as if it were an alteration product from it.

Chemical Composition.—The mineralogical composition of the dalmatianite shows that in general it is composed of minerals containing large proportions of iron, magnesia, alumina or silica, the predominance of which in the rock is confirmed by analyses I, II, and III, in Table I.[8]

A sample of cordierite separated from the dalmatianite was also analyzed and found to have the composition of Column IV. Of the above analyses, only I is typical dalmatianite; II and III are probably rhyolite, partly transformed to dalmatianite of the micaceous type.

Since no chemical analyses of the rhyolite, rhyolite breccia or andesite are available, it is not possible to determine precisely the chemical changes in these rocks required to transform them into dalmatianite. The rock is so abnormal, however, that it is obvious that the change in the composition of the rocks from which it was derived has been profound, consisting chiefly in a considerable addition of alumina, magnesia, and water, a large addition of iron, and a reduction in the content of lime and alkalies.

Origin.—The chemical analyses of the dalmatianite show that it is an unusual rock type different in composition from the Abitibi

[8] Walker, T. L.: *Op. cit.*, p. 10.

TABLE I.

	I	II	III	IV
SiO_2	30.00	60.52	67.94	44.46
TiO_2	.42	1.00	.45	.64
Al_2O_3	21.41	15.68	12.02	25.76
Fe_2O_3	7.06	.32	——	8.40
FeO	21.22	6.26	6.72	8.24
CaO	——	1.38	1.88	.62
MgO	11.54	7.34	1.74	7.42
MnO_2	.22	.14	.25	.47
NaO_2	.58	3.14	1.72	.74
K_2O	.68	2.24	2.46	.68
H_2O	6.84	1.93	2.16	2.73
CO_2	.13	.04	.08	
P_2O_5	.15	.17	.16	
S	.56	——	1.34	
Zn	——	——	1.61	
	100.81	100.16	100.53	100.16
O equiv. of S	.28		.67	
	100.53	100.16	99.86	
S.G.	3.04	2.81	2.87	

I. Collected from the dump at the Amulet Mine.
II. From a collection of Noranda rocks purchased from Mr. Cole and there called basic dalmatianite.
III. From the same collection, indicated as acid dalmatianite.
IV. Cordierite separated from dalmatianite.

volcanics or the rocks that intrude the volcanics. It replaces not only the rhyolite, rhyolite breccia, and andesite lavas but dikes of andesite and, on the northwest margin of the number 2 group of ore deposits, a dike of diorite 35 feet thick for a distance of 350 feet. These relationships, together with the fact that the original amygdaloidal, brecciated, scoriaceous, and other structures of the lavas are preserved in the dalmatianite, and that it is associated with areas of intense fracturing, prove conclusively that it is a product of rock alteration. Furthermore, its intimate association with the ore deposits indicates that it was formed by the solutions from which the ore was deposited.

The source of the mineralizing solutions from which the material introduced to form the dalmatianite and the ore deposits of the Amulet was derived cannot be satisfactorily discussed without a knowledge of the data available from all the ore de-

posits of the sulphide type in western Quebec. Only the relationships in the Amulet property bearing on the problem will, therefore, be presented here. There are three important intrusives in the region, so far as known, from which the emanations may have been derived. These are: (1) the diorite and quartz diorite, (2) the granodiorite or related intrusives, and (3) the late pre-Cambrian quartz diabase. Since the diorite dike adjoining the No. 2 mineralized area has been altered to dalmatianite, the dalmatianite cannot be older than the diorite, but the alteration of the diorite to dalmatianite does not preclude the possibility that the ore-bearing emanations came from the diorite magma, since emanations coming from the magma at depth may alter the consolidated upper part of the same intrusion. The granodiorite, and the diorite and quartz diorite, are closely related in composition and, although separate intrusions, are probably derived from the same magma by differentiation, so that whether the emanations came from the diorite or the granodiorite, the source is practically the same, except for the stage in differentiation at which they were evolved. The dalmatianite masses all lie at variable distances, from 600 feet in the case of the number 2 group of ore deposits to several thousand feet, west of a dike of late pre-Cambrian diabase that occurs along the eastern edge of the property. There is much evidence at the Amulet that the ore-bearing solutions ascended vertically along fractures and not diagonally from the east as they would almost certainly have done if they were related to the diabase dike. It is evident, therefore, that if the material introduced to form the dalmatianite is derived from the late pre-Cambrian diabase, it came from a larger mass of diabase magma directly below, and not by way of the dike.[9]

OTHER DEPOSITS OF THE AMULET TYPE.

Ore deposits with which cordierite, anthophyllite, and related minerals are associated are uncommon and, even where these minerals are present, it is not always certain that they are the

[9] For a discussion of the relationships of a similar dike at Noranda, see Price, Peter.: Bull. Can. Inst. Min. and Met., No. 263, pp. 138–140, 1934.

product of metasomatic alteration effected by the ore-bearing emanations. W. Lindgren [10] classifies deposits of this type as pyrometasomatic and believes that they are formed at high temperatures and under great pressure. He includes in the group the deposits at the Blue Hill mine in the state of Maine,[11] at Bodenmais, Bavaria,[12] at Falun,[13] Bersbo,[14] and Riddarhyttan in Sweden, and at Orijarvi in Finland.[15] Other deposits of this class not included in Dr. Lindgren's list are those at the Kaveltorp mines in Sweden. These, according to Magnusson,[16] are associated with cordierite, gedrite, and other magnesian minerals. He states that their formation has been characterized by a large-scale addition of silica, magnesia, fluorine, iron, copper, zinc, lead and silver to dolomite bodies intercalated in a potassic leptite complex.

CONCLUSIONS.

The ore deposits of the Amulet mine belong to the aggregates of sulphide ore masses of the Noranda type that occur here and there in western Quebec. The rocks in which they occur are chiefly Abitibi (Keewatin) lavas distributed in two groups, the older consisting of rhyolite and rhyolite breccia and the younger of andesite. Intruding these lavas are masses and dikes of diorite and quartz diorite; dikes, and a stock of granodiorite; a dike of quartz diabase of late pre-Cambrian age; and numerous dikelets and small sills of both acid and basic rocks. The age of most of these minor intrusions is known from the manner in

[10] Lindgren, Waldemar: Mineral Deposits, pp. 743–45, 1933.

[11] Lindgren, Waldemar: The Cordierite-Anthophyllite Mineralization at Blue Hill, Maine, and its Relation to Similar Occurrences; Proc. Nat. Acad. Sci., vol. II, pp. 1–4, 1925. Gillson, J. L., and Williams, R. M.: Econ. Geol., vol. 24, pp. 182–194, 1929.

[12] Hegemann, Friedrich, and Maucher, Albert: Abh. Geol. Landessuntersuchung am Bayer Oberbergamt, vol. II, pp. 1–36, 1933.

[13] Tornebohm, A. E.: Geol. Fören. Förhandl. vol. 15, pp. 609–690, 1893. Sjorgren, H. J., Geol. Fören. Förhandl., vol. 48, p. 75, 1926.

[14] Tornebohm, A. E.: Geol. Fören. Förhandl., vol. 7, pp. 562–598, 1884–5.

[15] Eskola, P.: Bull. Comm. geol. Findlande, vol. 8, number 40, 1914.

[16] Geol. Fören. Förhandl., vol. 52, pp. 407–416, 1930.

which they cut one another and from their relationships to the diorite and quartz diorite.

The ore deposits lie for the most part in the rhyolite breccia directly beneath the andesite contact but in places deposition also occurred in the andesite, as in the number 2 mineralized area, which is in the andesite at a point about 1,000 feet above the rhyolite breccia. The ore consists chiefly of pyrite, pyrrhotite, sphalerite, chalcopyrite, granular quartz, the various minerals of the dalmatianite, and a very small proportion of arsenopyrite, tetrahedrite and calcite. Of these the pyrite and arsenopyrite carry gold and were deposited first, whereas the chalcopyrite, tetrahedrite and galena carry silver and, with the sphalerite, were deposited last.

In association with the ore deposits and chiefly below them structurally, are large masses of a peculiar rock, which, because of the spotted appearance on its weathered surface, has been named dalmatianite. Microscopic examination of this rock shows that the peculiar spots consist of cordierite and that the dalmatianite, in addition to this mineral, consists largely of brown mica, aluminous anthophyllite (gedrite), occurring chiefly in beautiful rosettes or sheaf-like aggregates, green spinel, granular quartz, chlorite, magnetite, and pyrite, pyrrhotite, sphalerite and chalcopyrite. From the association of the dalmatianite with the ore deposits, and the manner in which it has replaced the rhyolite breccia and andesite lavas, the andesite dike rocks, and the diorite, it is concluded that the dalmatianite has been formed by hydrothermal alteration and that this transformation was effected by the emanations from which the ore was deposited.

The manner in which the ore deposits of the Amulet and the associated dalmatianite were formed was about as follows: The ore-bearing emanations ascended along fractures up to points in the rhyolite breccia matrix where it was scoriaceous or in the andesite where there was breccia. In these open rocks they spread out horizontally and ascended to where they were obstructed by impermeable barriers. This obstruction in the case of most groups of deposits (numbers 1, 3, 4, and 5) was a belt

of dense andesite lavas but in one case (number 2), which is in andesite, it was probably a dense flow of andesite or possibly, in the northwestern part, a northwesterly dipping dike of diorite. Deposition of the ore took place, no doubt, wherever cavities existed, but large masses of rock also must have been replaced by ore. The ore minerals which presumably were deposited at lower temperatures than the cordierite, gedrite, and other minerals of the dalmatianite were practically all deposited in a zone from 100 to 200 feet below the impermeable cover and chiefly in the upper part of this zone, whereas the dalmatianite was formed in its lower part or below the zone. It would seem, therefore, that the deposits of the Amulet exemplify a variety of zoning; but the upper zone, in this case, consists chiefly of the metallic minerals, and the lower zone of the non-metallic minerals of the dalmatianite.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, CANADA,
August 10, 1934.

ORIGIN OF THE GYPSUM DEPOSITS NEAR SANDUSKY, OHIO.

VERNER JONES.

THE workable deposits of gypsum are situated in Portage township, Ottawa County, Ohio, and the principal activity is centered about the village of Gypsum. The area embraces a portion of an irregular peninsula which is bounded on the south by Sandusky Bay and on the north and east by Lake Erie.

GENERAL GEOLOGY.

The surface in this portion of the state is characterized by low relief with a consequent scarcity of outcrops suitable for a detailed study of bed-rock geology. Many of the formation boundaries are therefore inferred and continuous sections are not exposed.

The gypsum occurs at numerous horizons interbedded with the dolomitic limestones of the Monroe formation (Silurian), which varies in thickness from 400 to 600 feet within the state. It is overlain to the east by Corniferous (Devonian) limestones and underlain to the west by Niagara limestone (Silurian). The Salina formation as developed in New York, Ontario, and Michigan is absent. The structure is a monoclinal dip to the east, which, except for local variations, is not more than a few feet per mile.

Deep wells show that calcium sulphate deposits underlie an extensive area in northern Ohio and that their interbedded character is a persistent feature. According to Orton,[1] cuttings from a deep well drilled at Sandusky in 1886 revealed a bed of gypsum 9 feet in thickness at a depth of 272 feet, and its presence was also noted at many points below this. He also reports [2] that at

[1] Orton, Edward: Report of the Ohio Geol. Survey, vol. 6, p. 697, 1888.
[2] *Idem*, p. 253.

Newberry, near Cleveland, deep well cuttings showed a 15-foot bed of anhydrite at 2154 feet and a 40-foot bed at 2300 feet, both associated with salt. He correlated these horizons with those worked for gypsum near Gypsum, Ohio. Orton postulates a deposition of anhydrite near Cleveland, and of gypsum alone in Erie and Ottawa counties. Subsequent developments at the present gypsum mines show that if these earlier conclusions and identifications are correct it would mean (proceeding from east to west) a deposition of anhydrite near Cleveland, of gypsum near Sandusky and of anhydrite at the site of present operations. It seems probable that identifications at the Sandusky well were not entirely correct, and although gypsum is known to occur in other areas at the depths noted, it is logical to expect larger proportions of the more stable mineral (anhydrite) at these depths, especially since it is known to predominate at depths varying from 100 to 150 feet near Gypsum, Ohio.

RELATIONS TO GYPSUM AREAS OF NEW YORK AND ONTARIO.

The gypsum deposits of New York, Ontario, and Ohio are Silurian in age. The rocks containing these deposits are known as the Camillus beds in New York and Ontario, and belong to the Salina formation of the Cayuga group.[3] The Camillus beds comprise dolomitic limestones and shales; the gypsum occurs in the upper portion of these beds and salt is found near the bottom. The Ohio deposits are situated in the Monroe formation of the Cayuga group. The gypsum is thought to occur in the lower portion of the formation, known as the Bass Island series,[4] and would therefore be the equivalent of the Bertie Waterline which immediately overlies the Camillus beds in New York and Ontario.[5]

[3] Newland, D. H.: The Gypsum Resources and Gypsum Industry of New York State. N. Y. State Mus. Bull. 283, p. 42, 1929. Dyer, W. S.: Geology of the Gypsum Deposits of South-Western Ontario. Ontario Dept. Mines, 34th Ann. Rept., vol. 34, pt. II, p. 42, 1925.

[4] Personal communication, Wilber Stout.

[5] Williams, M. Y.: The Silurian Geology and Faunas of the Ontario Peninsula, and Manitoulin and Adjacent Islands. Canada Geol. Surv. Mem. 111, p. 18, 1919.

The fact that the Ohio gypsum locality is on the opposite side of a relatively narrow portion of the basin of deposition from the New York and Ontario localities, would mean that conditions and kinds of deposition were not identical. Hence exact correlations are difficult. Since the Ohio gypsum occurs near the base of a formation (Bass Island series—lower Monroe), the equivalent of which overlies the formation (Camillus beds) in New York and Ontario containing the gypsum in its upper portions, then the original sediments of these deposits must be of approximately the same age.

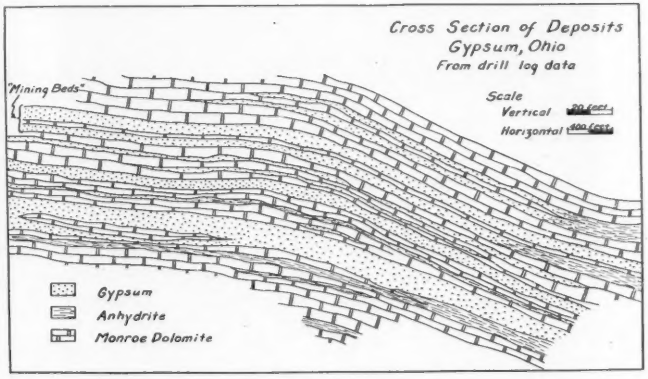

FIG. 1. Cross section of deposits, Gypsum, Ohio.

STRATIGRAPHIC DETAILS OF THE OHIO GYPSUM.

Underground workings and drill cores show the gypsum to be interbedded with the dolomitic limestones of the Monroe formation (Fig. 1). Few drill holes have penetrated deeper than 150 feet in search of gypsum, since below this depth considerable anhydrite occurs with the gypsum. Drill cores from greater depths show only minor amounts of gypsum with the anhydrite, and more commonly only the latter is found interbedded with the dolomite, so that if calcium sulphate occurs below these depths the anhydrous type would probably predominate.

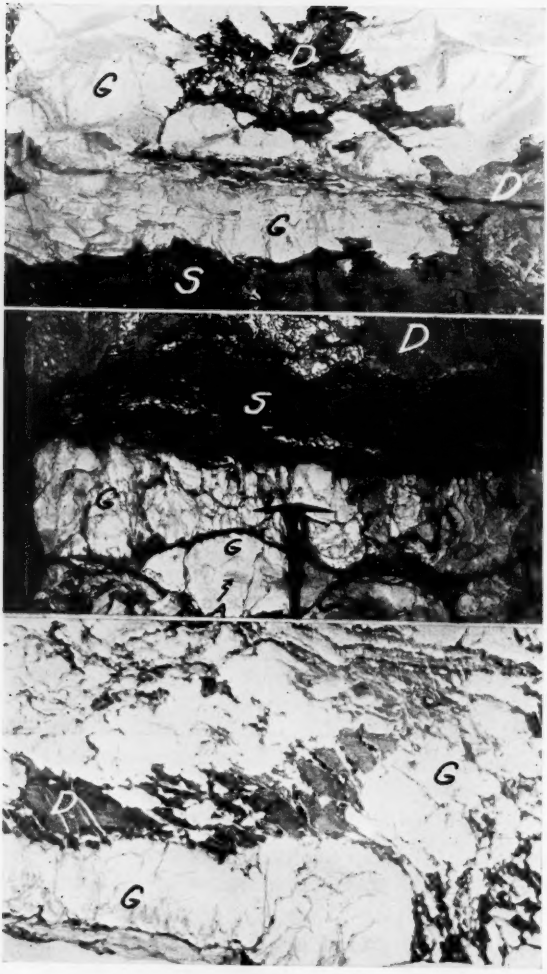

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FIG. 2. Underground view of upper member of the "mining beds." Gypsum (G) showing distortion and replacement of dolomite (D). A part of the middle shaly dolomite bed (S) is included.

FIG. 3. Underground view of lower member of the "mining beds." Impure gypsum and dolomite (D) at top. Middle shaly dolomite (S). Anhydrite kernel (A) altering to gypsum (G).

FIG. 4. Original beds of dolomite (D) fractured and replaced by gypsum (G). 3/7 natural size.

The beds worked at present lie approximately 50 to 60 feet below the surface in an essentially horizontal position and are locally known as the " mining beds." There are other extensive beds available but these lie deeper. The " mining beds " occupy a vertical distance of about 11 feet, and consist of an upper bed of commercial gypsum averaging 5 to 5½ feet in thickness, a middle bed of dolomitic shale with very little gypsum, and a lower commercial bed 4 feet in thickness. The entire 11 feet is removed in mining and the middle bed eliminated by sorting. The gypsum is mined by the " room and pillar " method.

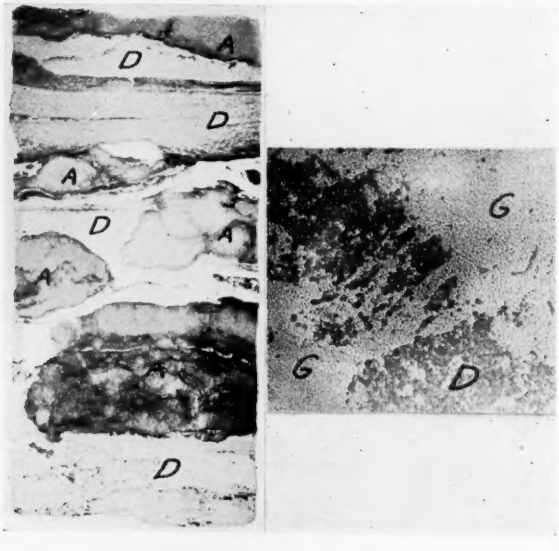
A considerable amount of dolomite occurs as an impurity in the commercial beds, appearing as crumpled bands in the gypsum which probably result from volume changes in the rock. This feature is best noted over a large face underground, although it can be readily observed in hand specimens (Fig. 4). It is noteworthy that this crumpling does not extend into the dolomitic limestones above or below but is confined to the gypsum beds. The theoretical increase in volume caused by the alteration of anhydrite to gypsum varies, according to different authorities, from 28 to over 60 per cent., although it is difficult to postulate the amount of increase that may take place under natural conditions.

Locally, pure bodies of white gypsum may occur within the commercial beds, which apparently represent the hydration of a relatively pure mass of anhydrite. At some places irregular masses of dolomite occur within the workable beds (Figs. 2, 3), but in general the character of the upper and lower beds is quite similar. The middle bed is composed of a slightly gypsiferous dolomitic shale which is persistent throughout the workings (Figs. 2, 3).

Anhydrite is of no importance within the " mining beds," although it is frequently found in the lower one, where it appears as blue kernels in the center of masses of white gypsum (Fig. 3). It apparently represents the remainder of an original mass of anhydrite which is being replaced by (hydrated to) gypsum. At greater depths drill cores show the " mining beds " to contain a

predominance of anhydrite (Fig. 1), in fact many of the cores show only dolomite and interbedded anhydrite (Fig. 5).

The underground workings exhibit many illustrations of the replacement of dolomite by gypsum. Irregular masses and tongues of gypsum project into the original dolomite (Fig. 2) and in addition numerous veinlets of gypsum cut the crumpled dolomite bands (Fig. 4). These irregular shapes of both the gypsum and the dolomite bands may be traced in part to the orig-



5 6

FIG. 5. Drill core showing relations of anhydrite (*A*) and dolomite (*D*) below depths of 100 feet. 1/2 natural size.

FIG. 6. Gypsum (*G*) replacing dolomite (*D*). Plane polarized light, ×33.

inal relations of the anhydrite and dolomite (Fig. 5). The expansion which accompanied the hydration process caused stretching, crumbling, and cracking of the dolomite bands, so that openings were made for the veinlets and irregular masses of gypsum.

MINERAL RELATIONSHIPS.

Dolomite-Anhydrite.—Drill cores show that in some cases the anhydrite forms lenticular masses, with indefinite boundaries, which are surrounded by dolomite. Microscopic examination of the contacts of the two minerals suggests that the dolomite may be replacing the anhydrite, but it seems unlikely that massive beds of anhydrite were extensively replaced by dolomite. One is inclined to assume that the anhydrite and the dolomite rock (whatever it may have been originally) were nearly contemporaneous accumulations and that the dolomite may be the product of diagenetic agencies operating on the original calcareous precipitate soon after deposition.

On the other hand, the Bass Island Series of Michigan is regarded as, for the most part, a detrital product from an original magnesian rock,[6] and although it is known to contain anhydrite no genetic observations of these details are known to the writer.

Anhydrite-Gypsum.—In the hand specimen, boundaries between these two minerals appear to be quite sharp, but in thin sections the change is seen to be gradational. The anhydrite shows typical lath-shaped crystals with much higher relief than the gypsum and a well defined "pseudo-cubic" cleavage.

In the gradational areas the gypsum replaces the anhydrite most effectively along this cleavage and tends to round off and gradually digest the original mineral. Here the gypsum has no well defined crystal form but is ragged in outline and might be designated as semi-pseudomorphic, since in many instances it retains a resemblance to the original mineral that it replaces. The alteration of anhydrite to gypsum may be regarded as a replacement process.

Dolomite-Gypsum.—Under the microscope, bands of originally continuous fine-grained dolomite are seen to be traversed by numerous irregular veinlets of gypsum in such a way as to separate the dolomite into isolated areas showing a definite linear arrangement which testifies to their original banded nature. This

[6] Newcombe, Robert B.: Oil and Gas Fields of Michigan. Mich. Dept. Conservation, Geol. Surv. Div., Pub. 38, Geol. Ser. 32, p. 71, 1933.

is also apparent in the hand specimen (Fig. 4). In some of the veinlets that cut the dolomite, the gypsum is much coarser grained than that which occurs between the original dolomite bands; but more commonly these gypsum veinlets are of the same texture as the surrounding gypsum areas (Fig. 6). It is presumed that when expansion took place during the change from anhydrite to gypsum the dolomite was broken so that spaces existed for the growth of large gypsum crystals. In such an instance fissure filling predominated, and replacement was of subordinate importance. The cross veinlets are then of two types, the replacement type and the filled-fissure type; they are closely related and commonly grade into each other.

Nearly all dolomite crystals, where in contact with gypsum, exhibit an irregular corroded boundary. This feature indicates that the formation of gypsum from anhydrite was accompanied by replacement of dolomite by gypsum (Fig. 6). It would be difficult to postulate the extent of this type of replacement, although it seems reasonable to believe that it was only of minor importance as compared to the replacement of anhydrite by gypsum.

ORIGIN.

The earlier proponents of theories of origin for gypsum deposits favored the action of acidulated waters on limestone as the probable process of formation. This theory received no consideration with reference to the Ohio deposits, as Newberry[7] early rejected it and postulated "precipitation from basins of water charged with salt, sulphate of lime, etc." This theory was subscribed to by Orton[8] several years later. This conclusion is probably correct, although these early observers believed the original precipitate to be the hydrous form of calcium sulphate. The preponderance of evidence now available indicates that the original precipitate of calcium sulphate was essentially, if not entirely, of the anhydrous type. If the dolomite which is associated with

[7] Newberry, J. S.: Report, Geol. Survey of Ohio, vol. 2, pt. I, p. 194, 1874.
[8] *Idem*, p. 699.

the anhydrite represents a detrital product, it was undoubtedly accumulating intermittently at the same time as the anhydrite.

The deposits at Gypsum, Ohio, are believed to represent hydration products that are the near-surface expression of deeper-lying anhydrite beds and lenses. Such a theory of origin is in accord with that ascribed to the gypsum deposits of New York and Ontario as well as to numerous other important deposits in the United States and Canada.

ACKNOWLEDGMENTS.

The writer is indebted to the United States Gypsum Company for permission to publish these results, and to Professor H. Ries for many helpful suggestions.

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ITHACA, N. Y.,
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THE NATURE AND OCCURRENCE OF CARBONATES IN VEINS.

G. H. CHARLEWOOD.

INTRODUCTION.

MUCH has been written on occurrences of carbonates in altered rocks and mineral veins, and various opinions have been expressed regarding the relations to depth and the mineral associations of several vein carbonates. It is surprising, however, to find how few definite determinations of the nature and composition of vein carbonates are found in geological reports on ore deposits. Many more detailed descriptions of these minerals are needed in order that their relations may be better understood. This investigation was undertaken in the hope that by making careful determinations of the composition of vein carbonates, in a number of series of specimens, some concrete data might be obtained. Difficulty was met in attempts to secure satisfactory series of specimens from mining camps, even where carbonates have been considered to constitute fairly abundant gangue minerals, due mainly to the uncertainty of collecting all the specimens of each series from one distinct vein.

Acknowledgments.—In connection with the preparation of this paper the writer takes pleasure in acknowledging the help and advice received from Dr. E. S. Moore, Professor of Economic Geology at the University of Toronto. He is also deeply grateful to Dr. H. E. McKinstry, formerly of Hollinger Gold Mines, Ltd.; Mr. E. W. Todd of the Lake Shore Mines Ltd.; Dr. T. M. Broderick of the Calumet and Hecla Copper Company; and Messrs. J. Barrington, formerly of the Nipissing Mining Company, O. H. Hershey, Consulting Geologist of the Bunker Hill and Sullivan Company, and Reno Sales, of the Anaconda Copper Company, for specimens from the mines of their respective companies.

CARBONATES IN VEINS.

An investigation of carbonates in veins deals with the distribution and composition of carbonates as affected by other minerals, wall rocks, and depth. There appears to be a regular change, with increasing depth, in the composition of some carbonates in certain veins.

Next to quartz, carbonates are the most common gangue minerals in veins, and they are ever-present constituents of gold veins in all parts of the world.

The gold-quartz veins of the Canadian shield range between the hypothermal and mesothermal types of deposits, and the majority of them contain some carbonate. Lower-temperature deposits in the pre-Cambrian which have a carbonate gangue include the silver-bearing veins of Cobalt, Ontario, and the copper deposits of Michigan.

Vein carbonates vary widely in composition. The common types are calcite, ankerite, ferro-dolomite and dolomite; less common is siderite, and still more rare are rhodochrosite and magnesite. The compounds included under dolomite and ankerite are especially abundant in the gold-bearing veins of the Canadian shield. Calcite is common, especially in silver veins. The calcium carbonate content of the ankerite and dolomite in the gold-quartz veins of the Canadian shield is rather characteristic, making up about 52 per cent. of the mineral, but the magnesium and iron content is variable. The calcite in this association has a fairly constant calcium carbonate content of about 95 per cent. Siderite is not commonly developed in gold-quartz veins, although abundant in silver-lead-zinc deposits. Rhodochrosite, with a few notable exceptions, rarely occurs abundantly in veins. It occurs more characteristically with siderite than with other carbonates, commonly in the mixed carbonate, mangano-siderite.

Carbonates in Hypothermal Veins.—Lindgren [1] divides hypothermal veins into four groups, but the gold-quartz veins are the only ones in which carbonates are important. The gold-bearing veins of the Canadian shield, of which the veins of the Hollinger

[1] Lindgren, Waldemar: Mineral Deposits, 3rd ed., 1928, p. 725.

gold mine are typical, are in this class. In many of the veins of the Hollinger mine carbonates are common. There were two distinct periods of carbonate deposition, one early in the sequence of vein formation, and one representing the last stage. The first and more important phase preceded the deposition of quartz.

There are two distinct types of carbonates at the Hollinger mine, with no intermediate members. One type consists of calcite with a fairly constant calcium-carbonate content of 95 per cent., the remaining 5 per cent. consisting of ferrous and magnesium carbonate with a trace of manganese carbonate. The mineral is light gray, fairly crystalline, and the value for ω is 1.658–9. The other type is ankerite, and in this mineral calcium makes up approximately 52 per cent.; practically the whole of the remainder consists of ferrous carbonate and magnesium carbonate, the proportions of which vary. Manganese carbonate is always present, but never in quantities of more than one per cent. The mineral is as a rule darker in color and less crystalline than the calcite, but the distinction, both macroscopic and microscopic, is difficult. The value for ω of the ankerite makes their distinction easy when differences in refractive indices are employed.

Since the deposition of carbonate was part of the vein-filling process, the source of the carbon dioxide was the same as that of the vein-filling hydrothermal solutions, which came from a magmatic source. There are two possible sources of calcium, iron and magnesium; either they were supplied by the wall rocks or they formed part of the hydrothermal solutions, or both. If the metals were supplied entirely or in part by the wall rocks, the composition of the carbonate would depend upon the original composition of the wall rock. The occurrence of calcite would be uncommon unless hydrothermal vein-forming solutions continued to supply it after the supply of iron and magnesium from the wall rock was exhausted. Such conditions would have resulted in carbonate types intermediate between ankerite and calcite, which have not been found in the course of this investigation. Most of the evidence favors the introduction of the entire carbonate material.

For a definite type of rock, if the wall rocks supplied the material, the composition of the carbonate formed would depend on the original composition of the rock, and the quantities of calcium, iron and magnesium in the carbonate would be different in different rock types. Analyses will be quoted later which show that the composition of the wall rock has no effect on the composition of the carbonate in the veins. Additional evidence pointing in that direction is supplied by the constant value for calcium carbonate in the ankerite gangue.

Calcite and ankerite may to a certain extent occur in the same vein, but there are veins in which the carbonate is predominately ankerite and others in which it is calcite. There occur abrupt transitions in some of the veins from a quartz-ankerite gangue to a quartz-calcite gangue. In the vein system 155–177, such a transition exists near the 2300-foot level. The upper 2300 feet of the vein has a quartz-ankerite gangue; below that depth the gangue is quartz-calcite. This condition may be due to a break in the vein in that neighborhood or to lateral movement either locally or over the whole system.

The mineral most intimately associated with ankerite is pyrite, and the relationships of these minerals suggest that the deposition of pyrite was in some way affected by the presence of ankerite. The quartz is generally white and comparatively unmineralized, as is also the calcite, whereas pyrite occurs abundantly in the ankerite that lines the walls of the vein, and in and around inclusions of ankerite in the quartz. Pyrite is disseminated in decreasing quantity from the ankerite lining into the country rock. The change from quartz-ankerite to quartz-calcite gangue is accompanied by a diminution in the quantity of pyrite, a feature which further suggests that an ankerite environment is favorable to an abundance of pyrite.

At certain points, much albite occurs where the transition takes place. According to Graton [2] and his associates, albite is the earliest of the vein-forming minerals. Rarely axinite and

[2] Graton, L. C., McKinstry, H. E. *et al.* Outstanding Features of Hollinger Geology. Bull. Can. Inst. Min. & Met., Jan., 1933, p. 12.

fouqueite occur with the calcite, but not with the ankerite. In a general way, the alteration accompanying the ankerite is sericitic and that with the calcite is chloritic. Tourmaline occurs with both types, as does scheelite to a certain extent, although the scheelite is more commonly associated with the ankerite. The quartz-ankerite and quartz-calcite veins occur in ill-defined zones, and according to Graton, most of the productive gold-bearing veins are within the quartz-ankerite zone. The veins in the quartz-calcite zone are nearly all barren.

The late period of carbonate formation at the Hollinger mine represents the last stage of vein formation at the mine. Veinlets of calcite occupy fault planes and other fissures, cutting all other minerals. The calcite is white, well crystallized, and may contain sphalerite.

Carbonates in Mesothermal Veins.—Carbonates occur abundantly in mesothermal veins, presenting an even wider range of composition than in hypothermal veins. There are three main types of veins in this class in which carbonates are prominent, namely, gold-quartz veins, silver-lead-zinc veins, and silver veins.

The carbonates of the gold-quartz veins are the same as those of hypothermal gold-quartz veins. The Mother Lode[3] of California is a classical example of the development of carbonate in and around mesothermal gold-quartz veins.

The carbonate gangue of silver-lead-zinc veins is principally siderite and manganosiderite. This type has no hypothermal equivalent. The veins at Slocan,[4] B. C., and of Coeur d'Alene[5] and vicinity, Idaho, serve to illustrate the carbonate gangue typical of that type of deposit. A typical analysis of siderite from a deposit in the latter district gave 79.13% $FeCO_3$, 13.94% $MgCO_3$, 3.83% $MnCO_3$, and 3.04% $CaCO_3$.

Silver veins are typified by those of the Cobalt district, Ontario, in which the gangue consists mainly of dolomite and calcite. A

[3] Knopf, Adolph: The Mother Lode System of California. U. S. Geol. Surv. Prof. Paper 157, 1929.

[4] Lindgren, Waldemar: *Op. cit.*, p. 645.

[5] Umpleby, J. B., and Jones, E. L., Jr.: Geology and Ore Deposits of Shoshone County, Idaho. U. S. Geol. Surv. Bull. 732, p. 32, 1923.

typical analysis of dolomite gave 51.75% $CaCO_3$, 45.6% $MgCO_3$, 2.4% $FeCO_3$ and 0.27% $MnCO_3$.

Carbonates in Epithermal Veins.—Carbonates from epithermal veins are not considered in this investigation. Quartz is the dominant gangue mineral, but calcite, dolomite and fluorite occur. Rhodochrosite is prominent in certain deposits. Siderite and ankerite are scarce.

Paragenesis.—Carbonates are known to have formed at all stages of vein formation; in places their period of deposition extended over a large part of the vein formation and at other places it was brief. In perhaps the greater number of veins that contain carbonates, they were formed late, but examination of several occurrences and study of much literature leads one to the conclusion that carbonates were early products of vein-filling more commonly than has hitherto been thought. In large camps such as Porcupine and Kirkland Lake, carbonates are among the earliest vein-forming minerals. Examples of other producing camps in which carbonates are prominent and in which they formed early in the sequence of deposition are Cobalt, Ontario; Mother Lode, California; and Coeur d'Alene and Woods River, Idaho. In most deposits in which the carbonates are late, they are present in subordinate quantity, but in deposits in which they are prominent, they are found to be the earliest vein-fillers. Such a condition prevails principally in gold-quartz and silver-lead-zinc veins.

Mineral Associations.—Minerals characteristically associated with carbonates in veins are much the same as those associated with them in carbonatized rocks. They have been discussed in the section on the Hollinger veins, which are typical of gold-quartz veins, and a similar association occurs in the veins of the Mother Lode, which belongs to the mesothermal class, except that scheelite and tourmaline are not characteristic of these veins. Chrome mica, which is common in dolomitic carbonatized rocks, is not found in vein carbonates.

COMPOSITION OF VEIN CARBONATES; EFFECT OF WALL ROCK.

Carbonates that replace country rock, forming carbonatized zones in the Canadian shield, have in general a higher total content of iron and magnesium than the carbonates in veins that traverse the same rock. In some cases the proportion of iron is greater than that of magnesium. In vein ankerite, however, calcium is always present in excess of magnesium, and magnesium always exceeds iron.

Rock replaced by carbonate may affect the composition of the carbonate that replaces it. This is not the case, however, with carbonate in the veins that traverse the same rock. Carbonates in veins that pass from one type of rock to another do not undergo a change in composition due to the change in composition of the wall rock. In Table I are analyses of calcite taken from veins that cut different types of rock, chiefly from the Hollinger mine. Some of the analyses represent the average of several taken from the same neighborhood.

TABLE I.

Location.	Vein Cuts.	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$FeCO_3$ and $MgCO_3$.
1. Matachewan....	Granite porphyry	96.65	0.26	1.04	1.30
2. Hollinger.....	Black slate	97.50	1.23	1.23	2.46
3. Hollinger.....	Porphyry	95.05	2.15	2.36	4.51
4. Hollinger.....	Dacite	96.04	2.06	1.81	3.86
5. Hollinger.....	Top of lava flow	94.81	2.01	2.73	4.74
6. Hollinger.....	Fine-grained pillow lava	94.99	2.11	2.33	4.44
7. Hollinger.....	Greenstone	96.60	0.50	2.70	2.75
8. Hollinger.....	Porphyry and greenstone	96.95	0.81	1.80	2.61

The quantity of manganese carbonate in each case is well below one per cent. and has no significance as far as wall rock or position in the vein is concerned, so it has been omitted in the above table.

The analyses of Table I suggest that the wall rocks had no pronounced effect upon the composition of the calcitic carbonates. If the wall rocks supplied all the iron and magnesium present, the total, calculated as carbonate, is in no case as great as 5 per cent., or as oxides, less than 3 per cent. It is reasonable to suppose that

at least some of the iron and probably also some of the magnesium, was supplied by the original vein-forming solutions. Finally, the rock types cut by the veins from which the carbonates in Table I were taken, with the exception of the porphyries, might well be expected to supply a proportion of ferrous oxide and magnesia in excess of 3 per cent., if the wall rocks played an important rôle in the formation of the vein carbonates.

A similar condition is found in the case of ankerite. The lowest calcium carbonate content in any calcite analyzed in the course of the investigation is 94.5 per cent. Only two specimens were found in which calcium carbonate exceeded 54.3 per cent.; both of these were taken from the same vein. Table II gives analyses of ankerites from veins cutting different types of rock.

TABLE II.

Location.	Vein Cuts.	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. Hollinger.....	Pillow lava	51.80	33.90	13.10	1.00
2. Hollinger.....	Greenstone	52.80	32.13	15.00	—
3. Hollinger.....	Greenstone	51.80	26.85	21.45	0.23
4. Goudreau.....	Feldspar porphyry	54.30	35.90	11.70	0.39
5. Larder Lake.....	Altered arkose	51.73	37.20	11.10	—

The composition of the wall rock does not materially affect the composition of the ankerite. The striking feature is the constancy of the proportion of calcium carbonate, which for most ankerites analysed is between 51 and 54 per cent. Such regularity of composition would not occur if the wall rocks controlled the composition, even if only the iron and magnesium were supplied by the country rock. The variations in the proportions of iron and magnesium can be attributed, as shown later, to causes other than the influence of the wall rocks. In one vein, analyses of the ankerite showed a marked change in the proportion of calcium carbonate, but the change is regular and not as would be expected if it were due to changes in the composition of the wall rocks. In every specimen of vein ankerite analyzed, the proportion of magnesia exceeds that of ferrous oxide.

Gradation in Composition of Vein Carbonates.

The discussion of the changes of composition of carbonates with depth will be confined to one deposit each of copper, gold, silver, and silver-lead-zinc ore. These are respectively, the deposits at the Calumet and Hecla copper mines, Michigan; the Hollinger gold mine, Timmins, Ontario; the Nipissing cobalt-silver mine, Cobalt, Ontario; the Bunker Hill and Sullivan silver-lead-zinc mine, Idaho.

Calumet and Hecla.—The geology of the Michigan copper deposits has been fully described by Butler and Burbank.[6] Suites of specimens of carbonates from the Kearsarge amygdaloid and the Calumet conglomerate, kindly furnished to the writer by Dr T. M. Broderick, showed no regular variation in composition down the dip of those lodes for a distance of six thousand feet. The carbonate is practically pure calcite, and conditions indicate constant temperature and pressure during the period of carbonate deposition as well as a uniform source of supply over the length of the lodes from which the specimens were taken. Manganese, iron and magnesium are present in very small quantities and in most cases calcium carbonate makes up over 99 per cent of the carbonate gangue. The results of the analyses follow in Tables III and IV.

Although the composition of the carbonate in these lodes does not show any regular change with depth, it is interesting to note that the magnesium carbonate and the manganese carbonate of the conglomerate are present in slightly larger quantity than in the carbonate of the amygdaloid, whereas the calcium is slightly lower. The ferrous carbonate is nearly the same in both, although the average for the amygdaloid is slightly higher than that for the conglomerate. These facts are significant, since the Kearsarge amygdaloid is a deeper formation than the Calumet conglomerate and probably was subjected to slightly higher temperature at the time of carbonate deposition. Thus the manganese and magnesium favor the upper and possibly slightly

[6] Butler, B. S., and Burbank, W. S.: The Copper Deposits of Michigan. U. S. Geol. Surv. Prof. Paper 144, 1929.

TABLE III.

CALUMET CONGLOMERATE.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 6th level	98.95	0.550	0.264	0.227
2. 43d level	98.96	0.788	0.132	0.113
3. 93d level	99.42	0.093	0.160	0.324

TABLE IV.

KEARSARGE AMYGDALOID.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 9th level	99.58	0.118	0.271	0.025
2. 24th level	99.63	0.133	0.221	0.018
3. 34th level	99.64	0.119	0.207	0.036
4. 40th level	98.92	0.215	0.148	0.720
5. 78th level	99.58	0.212	0.147	0.057
6. 81st level	99.25	0.497	0.228	0.022

lower-temperature zone of deposition, and the calcium and iron favor the lower zone. This condition is better illustrated by some gold-quartz veins which are discussed below.

Broderick [7] has observed differences in the nature of the carbonates that occur in some of the deep fissure veins and in the lodes. The carbonate that formed under the highest-temperature conditions found in the district is ankerite, which becomes dolomitic in lower-temperature zones. In the lodes themselves, however, the carbonate consists of calcite, which belongs to a phase of the mineralization separate from that to which the ankerite and dolomite belong.

Hollinger.—The veins of the Hollinger gold mine are representative of the Porcupine district, Ontario, and a number of specimens of carbonate from these veins were analyzed. There are many veins in this mine, but the three which are specially considered are numbers 155, 95 and 12. No. 155 is the most easterly of the three, No. 95 is central and No. 12 is at the west end of the mine. They are situated approximately 1500 feet apart on a nearly east-west line, although the veins themselves strike southwest.

[7] Broderick, T. M.: Fissure Veins and Lode Relations in Michigan Copper Deposits. ECON. GEOL., vol. 26, pp. 840–856, 1931.

The veins of the Porcupine gold area have been described by Burrows.[8] The results of the analyses of the vein carbonates are given in Tables V–VII.

TABLE V.
VEIN NO. 155.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 800-foot level	52.20	34.35	13.13	0.64
2. 2150-foot level	51.80	33.90	13.10	1.00
3. 2600-foot level	94.50	2.30	2.30	0.90
4. 2750-foot level	95.30	1.93	2.41	0.44

TABLE VI.
VEIN NO. 95.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 1250-foot level	50.50	34.37	14.76	0.30
2. 1850-foot level	51.90	32.40	15.84	0.25
3. 2300-foot level	51.90	32.20	15.60	0.44
4. 2750-foot level	52.00	31.80	16.00	0.26
5. 3350-foot level	51.50	26.85	21.45	0.23
6. 3950-foot level	96.31	0.50	2.66	0.35

TABLE VII.
VEIN NO. 12.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 550-foot level	52.60	32.03	15.00	0.30
2. 1100-foot level	60.31	23.30	15.87	0.39
3. 1850-foot level	67.10	19.77	12.50	0.23

Vein No. 155 contains a moderate quantity of both ankerite and calcite. The upper part of the vein is ankeritic and the lower part calcitic (Table V). This is in accord with observations at the mine, mentioned previously in this paper.

Vein No. 95 illustrates a series in which the composition of the carbonate changes with depth. The changes are not great, but large enough to be detected by analysis. There is a decrease in magnesium and an increase in iron with depth. The calcium carbonate remains fairly constant, but the proportion of manganese, which is small, does not change regularly.

[8] Burrows, A. G.: Ont. Dept. of Mines, vol. 33, pt. 2, 1924.

Vein No. 12 is unusual, due to the variation in the calcium carbonate, the quantity of which in the ankerite increases by 15 per cent with an increase of 1300 feet in depth. This is the only example encountered of a transition from the ankerite type to the calcite type. Magnesium carbonate increases with depth, in accord with the results from Veins 95 and 155 and from the Michigan lodes. The iron increases at first, but at the 1850-foot level drops to 12.5 per cent., which value is constant for all specimens from that locality. Vein 12 is marked by a scarcity of carbonates, compared with Veins 95 and 155. Albite is more abundant than carbonate.

The analyses given in Tables V–VII illustrate the two distinct types of carbonate that occur at the Hollinger mine. The carbonates from Vein 12 are the only ones that suggest a gradation between the two types, and even they are still definitely ankerite. The figures in Tables VI and VII suggest that in some well-defined veins there exists a gradual change in composition with depth, that change being an increase of calcium and iron and a decrease of magnesium.

There are two possible explanations for the abrupt change from calcite to ankerite in Veins 155 and 95. In the first place, although the veins are in general well defined, their detail is not so easy to follow. Where the veins occur close to one another, one cannot be absolutely sure that on a certain level the vein is the same that was examined two or three hundred feet above or below. The vein visited on one level may have pinched out before reaching another level or it may have been offset into another position. The solutions in one channel at a given depth may have been, at the time of vein formation, in a slightly different stage of precipitation than they were in another. Not much variation would be required to mask the small differences in composition that are shown in a good series. The second possibility is that the vein-forming solutions may have moved laterally in places, and not always continuously up vertical fissures. In this way it would be possible for the mineralization in the upper part of one of the present veins to differ from that of the lower part.

Nipissing.—A suite of three specimens was obtained from the Nipissing Mining Company, Ltd., at Cobalt, Ontario, through Mr. J. Barrington. They were taken from the Meyer Shaft, Vein 3009, in the conglomerate at varying distances above the Keewatin lavas and below the contact of the Nipissing diabase sill. Full descriptions of the veins of the area are given in Knight's report on the Cobalt silver area.[9] The total vertical range of the specimens is only 90 feet, yet they show a marked gradation in composition.

TABLE VIII.
NIPISSING MINE, MEYER SHAFT.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. 100 feet above Keewatin.....	51.75	45.60	2.40	0.27
2. 70 feet above Keewatin.....	53.50	42.90	3.15	0.56
3. 10 feet above Keewatin.....	54.34	40.58	4.50	0.48

Vein 3009 has a pink dolomite gangue which becomes less pink as the Keewatin contact is approached. The increase of calcium carbonate and ferrous carbonate and the decrease of magnesium carbonate with depth are identical with the conditions in some of the Hollinger veins, as is the irregularity of the manganese content.

There exist differences of opinion among those who have worked in the Cobalt field regarding the source of the vein-forming solutions, some believing that they came from the Nipissing diabase sill and hence, in the case of the Nipissing veins, descended from their source, while others believe that they ascended from a deeper source. If the latter is true the results given in Table VIII conform with those obtained from other camps, and if the former is true, the results are reversed.

The magnitude of the change of composition shown in Table VIII over such a short distance may seem unusual, but the veins are narrow, and as great a change can be expected over a short distance in a narrow vein as over a much greater distance in a large vein.

[9] Knight, C. W.: Geology of the Mine Workings of Cobalt and South Lorrain Silver Areas. Ont. Dept. of Mines, vol. 31, pt. 2, 1922.

Bunker Hill and Sullivan Mines and Vicinity, Idaho.—Analyses of carbonates from the ores of the Bunker Hill and Sullivan and some near-by deposits serve to indicate the nature of the siderite in that type of lead-zinc deposit. Full descriptions of the ore deposits of this region are found in the numerous reports which have been published, three of which are cited below.[10]

The writer is indebted to Mr. O. H. Hershey for kindly securing specimens of carbonates from several mines. Analyses of some of these carbonates are shown in Table IX.

TABLE IX.

	Altitude.	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	$MnCO_3$.
1. March Ore-shoot	3270	3.04	13.94	79.13	3.83
2. March Ore-shoot	2525	3.02	13.58	79.92	3.50
3. March Ore-shoot	800	4.66	9.15	84.93	1.23
4. Blue Bird type	3365	1.81	12.97	77.13	8.10
5. Blue Bird type	2765	2.07	14.00	77.70	6.24
6. Polaris mine	3650	1.35	11.34	82.10	5.25
7. Polaris mine	1000	1.17	7.95	85.85	4.98

Nos. 1, 2, and 3 are from the March ore-shoot of the Bunker Hill and Sullivan mine. The vertical difference represented by these specimens is 2470 feet, but the shoot has a low rake and the specimens represent a distance of one mile on the rake of the ore-shoot. The greatest regularity of change in the composition of the siderite over that distance is shown by the manganese, which decreases slightly with depth. Ferrous carbonate and calcium carbonate increase, whereas magnesium carbonate exhibits a characteristic decrease with depth.

Two specimens from a vein do not give a reliable indication of the trend of composition, but in the Blue Bird Lode, as in the March ore-shoot, manganese decreases and iron and calcium increase with depth. In this case there is also an increase of magnesium. The two specimens available from the Polaris vein,

[10] Ransome, F. L., and Calkins, F. C.: The Geology and Ore Deposits of the Coeur d'Alene District, Idaho. U. S. Geol. Surv. Prof. Paper 62, 1908. Hershey, O. H.: Genesis of Lead-Silver Ores in Wardner District, Idaho. Min. and Sci. Press, vol. 104, 1912. Umpleby, J. B., and Jones, E. L., Jr.: Geology and Ore Deposits of Shoshone County, Idaho. U. S. Geol. Surv. Bull. 732, 1923.

situated several miles east of the Bunker Hill and Sullivan, show increase in iron and decrease in manganese with depth. Calcium and magnesium both decrease.

The specimens from this camp are the only ones in which manganese was found to change consistently. Manganese is more characteristically associated with siderite than with any other carbonate. The results obtained from the Idaho siderite are on the whole in agreement with those from the quartz-ankerite veins of Porcupine and the two horizons of the Michigan copper deposits which have been discussed.

SUMMARY.

Carbonatization is a widespread phenomenon more typical of regions of gold-bearing quartz veins of the hypothermal and mesothermal types than of any others. This is especially the case in Ontario.

Vein carbonates present a wide range of composition. The composition of the wall rocks exerts very little and in many cases no influence on the composition of the carbonates in the veins. The composition of the carbonates is controlled by the composition, temperature and pressure of the vein-forming solutions at the time of vein-filling. A certain zoning of carbonate composition can be seen in some veins, as suggested by analyses given in Tables V to IX. The same magnitude of change does not occur over the same distance in all veins in any particular district, nor do the conditions that apply in one district necessarily apply in others. The results obtained from the four representative camps discussed in this paper agree to a certain extent. The proportion of ferrous carbonate in ankerite, siderite and dolomite increases with depth, as does calcium carbonate to a lesser degree. Magnesium carbonate decreases correspondingly. Manganese carbonate exhibited a regular decrease with depth only in the siderite of Bunker Hill and Sullivan.

From an economic standpoint it is interesting to note the association of carbonates, especially those formed early in the sequence of vein-filling, with mesothermal and hypothermal auriferous

quartz veins. The development of carbonatized rocks along the vein zones and in regions of gold-bearing quartz veins is characteristic of a large part of the Canadian shield. Ankerite is in nearly every case pre-ore. The carbonates of post-ore age are more commonly dolomite or pure calcite. An extensive study of the literature on hypothermal and mesothermal gold-quartz veins in various parts of the world supports the view that ankerite is the common pre-ore carbonate in that type of deposit.

Many more determinations of the composition of vein carbonates are needed to enable geologists to draw final conclusions regarding the relations of carbonates of different types to depth and to various associations of ore minerals.

KIRKLAND LAKE,
ONTARIO,
Sept. 4, 1934.

RELATIONS OF HYDROTHERMAL ALTERATION OF PORPHYRIES TO ORE DEPOSITION IN THE ALMA DISTRICT, COLORADO.[1]

QUENTIN D. SINGEWALD.

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INTRODUCTION.

It is now quite generally recognized that hydrothermal alteration of the wall-rocks, especially igneous rocks, is a well-nigh universal early stage in the deposition of metalliferous veins by solutions of igneous origin. In many mining districts, however, the igneous rocks show two types of alteration; one type is confined to the immediate vicinity of the veins and, within distances of a few feet to several hundred feet, grades into another type that is widespread, even extending throughout an entire district. The most familiar examples are where epithermal veins in Tertiary lavas have highly sericitized wall-rock that within a relatively

[1] Published by permission of the Director, United States Geological Survey, and of the Colorado Metal Mining Board.

short distance grades into rock showing widespread propylitization; but other examples are fairly common, including some where mesothermal veins are accompanied by both local and widespread types of alteration of intrusive rocks. The question naturally arises as to whether all the alteration took place at the same time, in which case the widespread type would be a marginal facies of the local type; or whether local alteration, whose intensity gradually diminishes outward from the veins, has been superimposed on an earlier, more widespread type of alteration not directly related to the ore deposits. Obviously either explanation could account for the observed gradation. There are seldom sufficient criteria to prove the answer conclusively, and so opinions have differed, as is pointed out and illustrated by Lindgren [2] in contrasting the views of Spurr and Finlayson. Lindgren states: "Finlayson does not accept Spurr's view that the vein-forming waters, filtered through rock masses, caused propylitization, but thinks that this alteration is due to solutions or gases rich in CO_2, which permeated the rocks immediately after solidification." Consequently, concrete evidence to answer the question in any one district should be of value as a step toward solving the general problem.

Among the wall rocks of many mesothermal veins in the Alma district, Colorado, there are five different intrusive porphyries of early Tertiary age. Field and petrographic evidence strongly supports the conclusion that each porphyry underwent an early, widespread, end-phase alteration; and that later, local alteration occurred as an early stage of ore deposition. This paper describes the nature of and the evidence for the two types of alteration in these rocks. Other features of the ore deposits will be described in the final report on the Alma district, to be published by the U. S. Geological Survey.

Material presented here was obtained while the writer, under the direction of B. S. Butler, was engaged in the co-operative work of the United States Geological Survey, the State of Colorado, and the Colorado Metal Mining Board. Many helpful

[2] Lindgren, Waldemar: Mineral Deposits, 4th ed., p. 461, 1933

suggestions have been made by Mr. B. S. Butler, Mr. G. F. Loughlin, and other members of the U. S. Geological Survey, especially those engaged in the Colorado work, to whom the writer is indebted.

GENERAL GEOLOGY.

The general geology of the Alma district has been adequately described elsewhere,[3] but for the reader's convenience a brief resumé is presented here to serve as a background for the rest of the paper. The basement rocks are pre-Cambrian schist and injection gneiss, granite, pegmatite, and granite gneiss. Unconformably overlying them are Paleozoic sedimentary rocks: the Sawatch quartzite (Upper Cambrian), consisting of quartzites in the lower part and transition beds of interbedded shales and limestones in the upper part; the Manitou limestone (Ordovician), which is the middle and upper parts of the "White limestone"; the Chaffee formation (Upper Devonian), which includes the Parting quartzite member below and the Dyer dolomite member or lower "Blue limestone" above; the Leadville or upper "Blue limestone" (Mississippian); and the Weber (?) formation (Pennsylvanian), composed of micaceous shale, quartzite, conglomerate, arkosic sandstone, and rare limestone. Early Tertiary (?) igneous rocks, which intrude all the above rocks, may be separated into two main divisions: the Buckskin Gulch stock and its associated dikes, and the groups of intrusive porphyries, which occur in dikes, sills, and, locally, laccolithic sills.

The district lies along the east flank of the Sawatch uplift, so the regional dip is eastward, but there are local folds and faults. The faults may be divided into two groups, major reverse faults and minor faults. The former group is represented by the Lon-

[3] Behre, C. H., Jr.: Revision of Structure and Stratigraphy in the Mosquito Range and the Leadville District, Colo. Colo. Sci. Soc. Proc. vol. 12, no. 2, pp. 37–57, 1929. Emmons, S. F., Irving, J. D., and Loughlin, G. F.: Geology and Ore Deposits of the Leadville Mining District, Colo. U. S. Geol. Survey, Prof. Paper 148, 1927. Patton, H. B., Hoskin, A. J., and Butler, G. M.: Geology and Ore Deposits of the Alma District, Park County, Colo. Colo. State Geol. Survey Bull. 3, 1912. Singewald, Q. D., and Butler, B. S.: Suggestions for Prospecting in the Alma District, Colo. Colo. Sci. Soc. Proc. vol. 13, no. 4, pp. 89–131, 1933.

don fault and the Cooper Gulch fault (Fig. 1). Minor faults are profuse, but in general they have small throws and die out within short distances, though the largest has a maximum throw

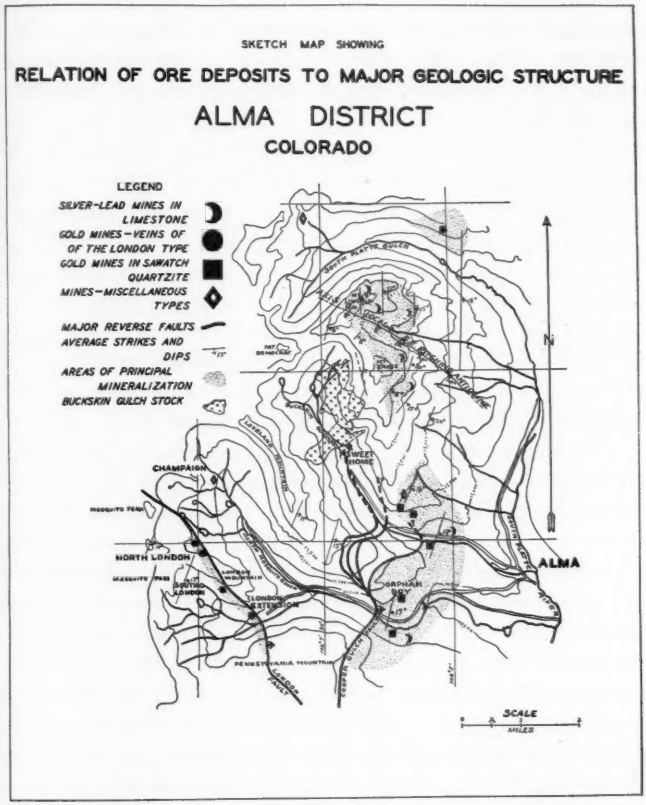

FIG. 1. Sketch map showing relation of ore deposits to major geologic structure, Alma district, Colo.

of 250 feet and is more than a mile long. The only conspicuous folds are long and narrow ones associated with the major reverse faults. They represent movement that at first produced

folds, but continued by rupturing the folds along faults which were accompanied by additional drag of the beds.

Two aspects of the geology have particular bearing on the problem discussed in this paper: the early Tertiary history, and the distribution of the ore deposits with respect to geologic structure. One of the early events of the Laramide revolution in the Mosquito Range was the intrusion of vast amounts of igneous material in the form of dikes in the pre-Cambrian rocks and sills in the sedimentary rocks. Most, at least, of the sill intrusion preceded the main period of folding and reverse faulting, but intrusion of dikes and stocks continued after initiation of the major reverse faults. A period of minor faulting followed the major reverse faulting, after which the latest of the intrusive porphyries—called the late White porphyry—was intruded chiefly in the form of dikes in both the pre-Cambrian and the Paleozoic rocks. Ore deposition followed soon after the intrusion of the late White porphyry. Minor faulting continued during and after ore deposition, perhaps to the present time.

With the exception of molybdenum, fully 99 per cent. of the production in the Mosquito Range has come from a narrow belt, scarcely more than 3 miles wide, that trends northeasterly from Leadville. Within this belt also are the known stocks and the majority of the dikes. Over 90 per cent. of the production from the east side of the range has come from three areas of principal mineralization, located where north to northwesterly trending major structures cross the northeasterly belt in the Alma district (Fig. 1). A fourth but relatively unimportant mineralized area, as well as most of the scattered small mines not within areas of principal mineralization, are located in the northeasterly belt but show no relation to other major structures, and there are some mines scattered elsewhere throughout the range. Thus, major structures clearly influenced the general distribution of ore-depositing solutions throughout the district. In addition, minor faults localized all the individual ore bodies.

PETROLOGY OF PORPHYRIES NOT ADJACENT TO VEINS.

This section of the paper describes the general petrology, including alteration phenomena, of the intrusive porphyries beyond the influence of the alteration that lies adjacent to the veins.

For this purpose the porphyries are divided, as at Leadville, into two main groups—the Gray porphyry group and the White porphyry group, and only those features pertinent to the present problem are described.

Gray Porphyry Group.

Classification.—The Gray porphyry group in the Alma district has been mapped in three cartographic units: Lincoln porphyry, quartz monzonite porphyry, and monzonitic-diorite porphyry.

The Lincoln porphyry is characterized by large pink orthoclase crystals among its phenocrysts. It is similar in texture and composition to certain dikes which are genetically associated with the Buckskin Gulch stock but are only considered incidentally in this paper. The other two porphyries, in which large orthoclase crystals are absent, differ from each other in that the monzonitic-diorite porphyry has a dark color, a fresh appearance, a relative abundance of hornblende, and an almost total absence of visible quartz.

Distribution.—The Gray porphyries occur mainly as sills in the sedimentary rocks and dikes in the pre-Cambrian rocks, but there are some differences in distribution that should be noted. The quartz monzonite porphyry is widely distributed, being abundant everywhere in the district except in the eastern part. Sills of it occur in all the sedimentary formations but are most common in the Cambrian quartzites and in the Weber (?) formation. The Lincoln porphyry is absent in the sedimentary rocks between the Cooper Gulch fault and the crest of the range but is abundant throughout the rest of the district. Sills of it are most abundant and thickest in the basal part of the Weber (?) formation, but occur at other stratigraphic horizons. Sills of monzonitic-diorite porphyry, which are most common in the Cambrian quart-

zites, underlie most of Loveland Mountain, the southeast portion of Mt. Bross, and the east slope of Mt. Lincoln, but elsewhere this porphyry is scarce.

Most occurrences of the Gray porphyries are considerably less than 100 feet thick; locally, however, laccolithic sills of Lincoln porphyry and of quartz monzonite porphyry, in the basal beds of the Weber (?) formation, attain a thickness of several hundred feet.

Original composition.—The average original compositions of the Gray porphyries, excluding accessory minerals, are shown in Fig. 2. The monzonitic-diorite porphyry ranges between what

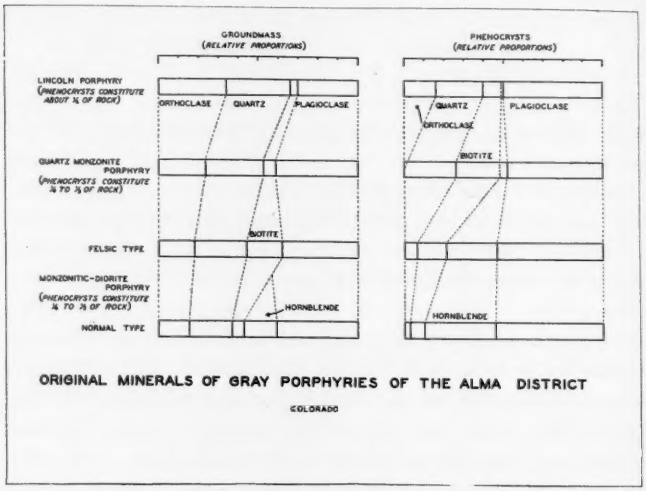

FIG. 2. Original minerals of the gray porphyries in the Alma district, Colorado.

are here called the normal variety and the felsic variety, most occurrences having approximately the composition of the former. The composition of each variety was obtained by making several Rosiwal analyses of thin sections and comparing these with the mode calculated from a chemical analysis; the results may be

taken as substantially correct, for the rocks have undergone only moderate hydrothermal alteration. The compositions shown for the quartz monzonite porphyry and the Lincoln porphyry were obtained by Rosiwal analyses, but they are only approximate because these rocks almost everywhere are extensively altered.

Several features, apparent from Fig. 2, are worthy of special note. Except for orthoclase in the Lincoln porphyry, the same minerals constitute the phenocrysts in each porphyry, and the same is true of the accessory minerals. Furthermore, the groundmass of each porphyry is more felsic than its phenocrysts, showing that the trend in crystallization was toward a concentration of silica and the alkalis.

There are several reasons for regarding the phenocrysts as intratelluric. In the first place, there is a distinct break in grain size between phenocrysts and groundmass, and nowhere is there a margin without phenocrysts followed by a transition zone in which the phenocrysts gradually increase in size toward the center of a sill or dike. Secondly, the plagioclase phenocrysts (where not albitized) in all the Gray porphyries are calcic andesines, with conspicuous oscillatory zoning that shows too many alternations in composition to have formed *in situ,* especially in sills. In addition, certain characteristic features common to the same mineral in different porphyries suggest a common magmatic source.

Alteration.—No thin sections of the Gray porphyries are free of hydrothermal alteration products, but the intensity of the early alteration now under consideration varies in the different porphyries and to some extent in different occurrences of the same porphyry. Comparison of different degrees of alteration shows that the process on the whole was one of selective replacement, with each original mineral developing its own secondary products. The texture, therefore, is preserved fairly well, and original plagioclase can be distinguished from original ferromagnesian constituents even where alteration has been fairly extreme. Of course, there was some irregular spreading of secondary minerals through the rocks, so that retention of the original texture has not been perfect.

Table I lists the hydrothermal alteration products of each original mineral, except quartz and the accessory minerals. The products are essentially the same in each porphyry, except that the original plagioclase has nearly everywhere been converted to albite in the Lincoln and quartz monzonite porphyries but has almost nowhere been converted in the monzonitic-diorite por-

TABLE I.

HYDROTHERMAL MINERALS (END-PHASE) IN GRAY PORPHYRIES OF THE ALMA DISTRICT, COLORADO.

Original mineral		Plagioclase	Hornblende	Biotite	Orthoclase
Alteration products		Sericite White carbonate ± Albite($Ab_{90}An_{10}$) Epidote Clinozoisite Chlorite	Chlorite Epidote White carbonate Leucoxene ± Sericite Ferruginous carbonate Magnetite(?)	Green mica Chlorite Epidote Leucoxene and/ or White mica White carbonate Sericite ± Ferruginous carbonate Rutile Magnetite(?)	Sericite White carbonate
Extent altered in	Lincoln porphyry	Intensely	Completely	Almost completely	Slightly
	Quartz monzonite porphyry	Moderately to intensely	Completely	Intensely to completely	Slightly
	Monzonitic-diorite porphyry	Moderately	Moderately	Slightly to moderately	Slightly

phyry. The intensity of alteration, however, differs in each porphyry, as is indicated in the table. It should be noted that the intensity of alteration indicated for the Lincoln porphyry refers to occurrences that are not closely associated with the Buckskin Gulch stock, for in the pre-Cambrian rocks of Buckskin Gulch there are certain dikes (which really are offshoots of the stock and, therefore, not part of the intrusive porphyries now under discussion), that have undergone little hydrothermal alteration.

A comparison of specimens of any one porphyry showing different degrees of alteration shows that the action took place progressively and may be divided into four stages. During the first stage the plagioclase was albitized and green mica developed. Albitization did not take place universally but is confined to localities where the solutions were especially active, as shown by the profuse development of other secondary minerals. It was

followed by introduction of sericite and subordinate amounts of clinozoisite and epidote into the plagioclase; of chlorite, epidote, and small amounts of sericite and leucoxene (?) into the hornblende; and of chlorite, epidote, white mica, and small amounts of leucoxene (?) and rutile into the biotite. Small amounts of pyrite formed, probably during this second stage. In the further alteration of the third stage, white carbonate and more sericite replaced feldspar, remnants of the ferromagnesian minerals, epidote, and chlorite; and minute masses of ferruginous carbonate formed in the ferromagnesian minerals and their pseudomorphs. The fourth stage is represented by veinlets and large grains of white carbonate with a little quartz, and rarely, chlorite. Textural criteria indicating the above sequence have been presented elsewhere.[4]

Relative Ages.—The felsic variety of monzonitic-diorite porphyry cuts quartz monzonite porphyry at several places in the Alma district, but Patton[5] reports that at one place, on Pennsylvania Mountain, the normal variety is cut by quartz monzonite porphyry. Likewise, the Lincoln porphyry in many places cuts quartz monzonite porphyry, yet the opposite occurs in two localities. Thus, field relations in the Alma district suggest that the sequence of eruptions was overlapping but in the general order:—monzonitic-diorite porphyry (oldest), quartz monzonite porphyry, Lincoln porphyry. This sequence corresponds with the general sequence throughout the Tertiary intrusive belt of Colorado, as determined by Lovering.[6]

Local petrographic data accord with the field evidence. As seen in Fig. 3, the groundmass of each porphyry is more felsic in composition than its phenocrysts, so the trend of crystallization in the magma reservoir was from mafic to felsic. It follows that the relative ages of the porphyries should be in the order of their relative compositions from mafic to felsic.

[4] Singewald, Q. D.: Alteration as an End Phase of Igneous Intrusion in Sills on Loveland Mountain, Park County, Colorado. Jour. Geol., vol. 40, pp. 24–25, 1932.

[5] Patton, H. B., Hoskin, A. J., and Butler, G. M.: *Op. cit.*, p. 92.

[6] Lovering, T. S.: Geology and Ore Deposits of the Breckenridge Mining District, Colorado. U. S. Geol. Survey, Prof. Paper 176.

With rare exceptions, all the Gray porphyries are as much displaced by minor faults as are the sedimentary strata; hence, the porphyries were intruded prior to the main period of minor faulting. Major reverse faults, likewise, displace monzonitic-diorite porphyry and quartz monzonite porphyry equally with the sedimentary strata, but nowhere in the Alma district is the Lincoln porphyry adjacent to a major reverse fault.

White Porphyry Group.

Classification.—The White porphyry group consists of an early White porphyry, corresponding to the "White porphyry" of the Leadville Professional Paper, and a late White porphyry.

In typical early White porphyry, small to medium-sized quartz grains and dark muscovite flakes are sparsely scattered through a whitish-gray, soft, dense groundmass. Local varieties range from rock having no phenocrysts to rock containing intensely altered phenocrysts of feldspar in addition to quartz and, in places, dark muscovite. The late White porphyry, except where age relations can be determined, is indistinguishable from the more porphyritic early White porphyry.

Distribution.—The early White porphyry occurs mainly as sills in the sedimentary rocks, especially in the basal part of the Weber (?) formation. It is present throughout the area between the London fault and the crest of the range and at a few scattered localities in the eastern part of the district. On the west side of the Mosquito Range, this porphyry is widespread in sills that locally attain great thickness. One sill southeast of Mt. Sherman attains a maximum thickness of 1,500 feet.

The late White porphyry, in contrast to all the other porphyries, occurs mainly in the form of dikes in the sedimentary rock as well as in the pre-Cambrian rocks. All the dikes are less than 100 feet wide. Most occurrences in the Alma district are in the northeasterly belt that contains the bulk of the ore deposits.

Composition.—The groundmass of both White porphyries is composed of exceedingly small, anhedral grains of orthoclase, quartz, sericite, very sodic plagioclase, and white carbonate. Ac-

cessory minerals are apatite, zircon, leucoxene (?), rutile, magnetite, and pyrite. Phenocrysts are scarce, but in addition to quartz and muscovite, there are in places matted sericite aggregates, some of which probably are pseudomorphs after feldspar. In the late White porphyry some of the pseudomorphs contain remnants of albite (close to $Ab_{90}An_{10}$) or orthoclase.

The exact original composition of the White porphyries cannot be determined because of the intense hydrothermal alteration they have suffered everywhere. Nevertheless, the predominance of quartz among the phenocrysts, the complete absence of chlorite or epidote as secondary minerals, and the abundance of quartz and orthoclase in the groundmass, show that the rocks were quite felsic. On the other hand, in spite of the intense alteration, some plagioclase is retained in the groundmass, and the minor amounts of secondary titanium minerals, especially rutile, reveal the former presence of at least some ferromagnesian constituents. Hence, the rocks probably were rather felsic quartz monzonites or granites close to quartz monzonite in composition.

Alteration.—Both porphyries have everywhere suffered intense hydrothermal alteration which formed sericite, subordinate amounts of white carbonate, and minor amounts of pyrite, leucoxene (?), and rutile. The relations of sericite and carbonate to the original quartz, orthoclase, and plagioclase show that the secondary minerals replaced plagioclase and ferromagnesian constituents extensively, orthoclase moderately, and quartz only slightly.

Relative Ages.—In the Alma district, definite age relations of the early White porphyry to the Gray porphyries could be observed at only one place, on the east slope of Mt. Lincoln, where quartz monzonite porphyry cuts early White porphyry. On the west side of the Mosquito Range, however, where more extensively developed, the early White porphyry is older [7] than all the Gray porphyries. In the Alma district the early White porphyry is displaced as much as the sedimentary strata by both the major reverse and the minor faults.

[7] Emmons, S. F., Irving, J. D., and Loughlin, G. F.: *Op. cit.*, p. 43.

At many places the late White porphyry shows no displacement on pre-mineral faults, but ore-shoots occur in it at the Kentucky Belle mine, a small mine located in the upper part of Buckskin Gulch. On the other hand, at Leadville and at Climax there are rocks resembling the late White porphyry of the Alma district which were intruded after ore deposition. Hence, this porphyry was intruded after the period of pre-mineral faulting, just before and perhaps during deposition of the ores. This relation to faulting accounts for its occurrence in the sedimentary rocks chiefly as dikes, in contrast to all the other porphyries, which were intruded before the main period of faulting and therefore formed sills in the sedimentary rocks.

INTENSITY OF WIDESPREAD TYPE OF HYDROTHERMAL ALTERATION.

None of the porphyries anywhere in the district are free of hydrothermal minerals, yet there are differences of intensity in the alteration (of the type not localized adjacent to veins). In general, the dikes of any one porphyry are less altered than the sills, but there are no other concomitant variations. The early White porphyry, throughout all occurrences, has been somewhat more intensely altered than any other porphyry. The monzonitic-diorite porphyry, on the other hand, is everywhere only moderately altered. Slight variations in the intensity of its alteration are more closely related to mineral composition than to geographic distribution, the felsic variety being slightly more altered than the normal variety. Quartz monzonite-porphyry dikes in the pre-Cambrian rocks of the upper parts of Platte, Buckskin, and North Mosquito Gulches and sills in the Cambrian quartzites near the top of Loveland Mountain show only moderate alteration, but throughout the rest of the district this porphyry is intensely altered. Thus, the intensity of alteration seems to vary more with geographic location than any other factor. The least altered occurrences are fully as much altered as any of the monzonitic-diorite porphyry, and the most altered ones are somewhat less altered than the White porphyries.

The Lincoln porphyry, wherever it occurs in the sedimentary

rocks, is intensely altered to an extent approximately equal to the most altered occurrences of quartz monzonite porphyry. In the pre-Cambrian rocks of Buckskin Gulch, there are some dikes essentially identical with the Lincoln porphyry in texture and composition that are only slightly altered, but these dikes are closely associated with the Buckskin Gulch stock and therefore are really not part of the group of intrusive porphyries discussed in this paper.

The late White porphyry, in spite of its almost universal occurrence as dikes, is everywhere intensely altered to an extent only slightly less than that of the early White porphyry.

END-PHASE ORIGIN OF THE WIDESPREAD TYPE OF HYDROTHERMAL ALTERATION.

The seven salient features that bear on the origin remote from mineral veins are summarized below:

1. The intensity of alteration bears no relation to the relative ages of the porphyries. Both the youngest and oldest are more altered throughout the district than those of intermediate age, and the oldest of the Gray porphyries is prevailingly less altered than the two younger ones. The same is true locally. Thus, in the area west of the London fault an early White porphyry sill in the basal part of the Weber (?) formation is everywhere more altered than a contiguous one of quartz monzonite porphyry; on the lower part of Loveland Mountain, two sills of quartz monzonite porphyry in the Cambrian quartzites are more altered than a sill of monzonitic-diorite porphyry in the same rocks; and on the upper part of Loveland Mountain, sills of quartz monzonite porphyry in the Cambrian quartzites are less altered than early White porphyry dikes that cut them. Other examples could be cited.

2. The intensity of alteration, as is apparent from the examples just cited, bears no relation to the chemical composition of the wall rocks of the intrusive porphyries.

3. The intensity of alteration bears no constant relation to the major structures (Fig. 1) that influenced the areas of maximum ore deposition. Although the intensity of alteration of the sills

of quartz monzonite porphyry does decrease away from the area of mineralization on lower Loveland Mountain, no similar relation exists elsewhere.

4. Not only are there no structural foci, but there are no foci of any sort around which all the porphyries show a corresponding increase or decrease in the intensity of alteration. Such variations as exist for one porphyry do not conform geographically with variations in any other.

5. All the sills are considerably jointed, and these openings doubtless had some influence on the amount of alteration, but there is no constant relation between the extent of jointing and the intensity of alteration in a sill; for example, in the area west of the London fault, jointing is more conspicuous in the quartz monzonite porphyry than in the early White porphyry, yet the White porphyry is the more intensely altered.

6. There is a close relationship between composition and intensity of alteration. Thus, the normal facies of monzonitic-diorite porphyry is prevailingly less altered than the felsic variety, which in turn is less altered than the still more felsic quartz monzonite and Lincoln porphyries. The early White and the late White porphyry, both of which were probably more felsic than any of the Gray porphyries, are even more intensely altered. It is apparent, therefore, that the richer the original rock was in silica and the alkalis, the more intense has been its alteration.

7. The relationship between composition and intensity of alteration becomes especially significant when it is remembered that, in all the porphyries, plagioclase and ferromagnesian constituents are much more altered than orthoclase, which in turn is more altered than quartz. Hence, the intensity of alteration of each porphyry as a whole *does not* depend on the percentage of easily replaced minerals.

The foregoing features demonstrate conclusively that in each porphyry the kind of hydrothermal alteration under discussion occurred as an end phase of intrusion, produced by solutions that either were contained in the magma *in situ* or followed the same courses as the magma and did not spread appreciably from the

porphyry into the surrounding rocks. The magmas richest in silica, and the alkalis, apparently supplied the greatest quantity of solutions. Had the solutions not followed the same paths as the magmas with which they are associated, any older rock containing a larger percentage of easily altered minerals would have become more altered than a younger one containing a smaller percentage. Moreover, had all the alteration been accomplished during one period—presumably during an early stage of ore deposition—the extent of alteration in different rocks at the same locality should depend on their relative susceptibilities, and there should be some consistent variation in all the porphyries with respect to recognizable foci throughout the district.

HYDROTHERMAL ALTERATION LOCALIZED NEAR ORE DEPOSITS.

In addition to the widespread end-phase alteration, the porphyries in the Alma district have suffered intense hydrothermal alteration which is localized in the immediate vicinity of metalliferous deposits. Several mines having different types of ore-bodies at widely scattered localities in the district will serve as examples from which may be drawn certain conclusions regarding the later alteration.

London Mine.—The most productive mine in the district has been the London, which includes the North London, South London, and London Extension workings. These and other smaller workings on the same ore-bodies are located at London Mountain (Fig. 1) within 800 feet of the London fault, on the west or footwall side of the London fault. The ore-bodies are almost entirely veins composed of quartz with subordinate amounts of simple sulphides, native gold, which is the chief metal of value, and altered remnants of the country rock. They occur mainly in two interfingering sills of early White porphyry and quartz monzonite porphyry, which contain numerous lenticular inclusions and layers of Weber (?) shale and quartzite. The dip of the veins, though steep to the southwest, is a little less than the dip of the strata, which are upturned against the London fault. Thus, the principal wall rocks are the two porphyries and the sedimentary rocks.

In and immediately adjoining the veins, hydrothermal alteration has converted both porphyries to quartz and sericite, with only insignificant amounts of accessory minerals. The groundmass of the quartz monzonite porphyry has a micro-granular fabric in which small unoriented sericite flakes are intimately intergrown with quartz. Quartz phenocrysts are slightly replaced and transected by sericite, but on the whole have been little changed. The other phenocrysts, however, are completely replaced by matted aggregates of sericite, mostly somewhat coarser grained than the sericite of the groundmass, which have somewhat destroyed the boundaries of the original grains. Some of the sericite aggregates, presumably those that originally were biotite, are full of minute rutile needles. Alteration of the early White porphyry closely resembles that of the quartz monzonite porphyry, except that sericite aggregates representing phenocrysts are extremely scarce. A short distance from the veins, small granules of white carbonate, in subordinate amounts, accompany the sericite and quartz. The sericite-quartz-carbonate rock in turn grades through a distance of several hundred feet into porphyry with only end-phase alteration products. The exact width of the transition zone cannot be stated, for there are so many small unproductive veins and veinlets throughout the mine that at no place is it certain whether the intensity of alteration is a function of the distance from an exposed vein or veinlet or from a closer one that has not been cut by the mine workings; furthermore, the width seems to vary somewhat throughout the mine.

The sedimentary rocks show comparatively little alteration. The shales were to some extent recrystallized, the quartzites probably impregnated with small amounts of sericite, and the carbonaceous material in places converted to a graphitic substance.

Vein-quartz, with or without sulphide minerals, corrodes and transects fragments of sericitized porphyry that are in the veins, so the sericitization must have taken place before deposition of the vein minerals. But on the other hand, the distribution of the highly sericitized rock conforms so closely with the distribution of the veins that the sericitization must be regarded as a phase of ore

deposition. The changes in the early White porphyry are not conspicuous megascopically because this rock had already been rather intensely sericitized by end-phase alteration, but the resultant bleaching of the quartz monzonite porphyry is so conspicuous as to be a useful guide in outlining areas worthy of prospecting.

In summary, it may be concluded that the earliest stage of ore deposition was sericitization of sufficient intensity to convert the porphyries to sericite and quartz in and immediately adjoining the veins.

Orphan Boy Mine.—The Orphan Boy mine, located on the lower slope of Loveland Mountain (Fig. 1), has yielded ores valuable chiefly for gold, although silver was more abundant in actual ounces per ton. The total production is about 1/100 that of the London mine, yet it is one of the most valuable mines of its type. The ore bodies are replacement veins along minor faults in the Cambrian quartzites. These veins are narrow and unproductive except at one favorable horizon, immediately below a sill of quartz monzonite porphyry, where there are ore shoots, not more than 20 feet wide, formed by replacement of the quartzite wall rock. The hypogene vein minerals are ferruginous dolomite, simple sulphide minerals, and quartz.

At places, the quartz monzonite porphyry in and adjoining the veins was bleached to a rock that is virtually identical with the most highly sericitized rock at the London mine. Elsewhere, however, subordinate amounts of white carbonate, minor amounts of leucoxene, and ferruginous carbonate are also present. The last two minerals are confined to the pseudomorphs after former ferromagnesian constituents. Rock showing the above alterations grades within a few feet of the veins into quartz monzonite porphyry that has an abundance of end-phase alteration products. Quartzite remnants in the ore have been impregnated with small amounts of sericite distributed interstitially to the quartz grains. The sericitized porphyry is corroded and transected by vein quartz that is older than the sulphide minerals and the dolomite. Thus, the early age of the wall-rock alteration and its localization within

a few feet of the veins show that here, too, sericitization was a first stage of the ore deposition.

Sweet Home Mine.—The Sweet Home mine, located in Buckskin Gulch, has produced a small amount of copper ore from nearly vertical veins along minor faults that intersect pre-Cambrian granite and Tertiary quartz monzonite porphyry. The veins consist of quartz, hübnerite, fluorite, rhodochrosite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, bornite, chalcocite, and fragments of altered country rock.

The quartz monzonite porphyry in and adjoining the veins has been converted to a rock in which the original texture is moderately well preserved but which now consists of sericite, quartz, subordinate pyrite, and rare white carbonate and accessory minerals. Sericite has replaced quartz and the accessory minerals to a slight extent but has completely replaced the other minerals. Within a few inches to several feet from the veins the porphyry shows somewhat different alteration. Original plagioclase phenocrysts have been completely replaced by matted aggregates of small sericite flakes accompanied by minor amounts of white carbonate; the ferromagnesian phenocrysts have been converted to moderately coarse-grained white mica intergrown with sericite and subordinate amounts of leucoxene, ferruginous carbonate, and white carbonate; the matrix consists of orthoclase, quartz, and sericite. Rock of this type grades within a few feet into quartz monzonite porphyry showing moderate end-phase alteration.

The pre-Cambrian granite, like the porphyry, in and adjoining the veins, is converted to sericite, quartz, minor pyrite, and rare accessory minerals. The sericitized granite grades, through several feet, into normal granite consisting of calcic oligoclase, quartz, orthoclase, microcline, biotite, accessory minerals, and small amounts of secondary sericite, chlorite, epidote, and pyrite.

The highly sericitized porphyry and granite are transected and corroded by vein-quartz that is older than any of the other vein minerals. Some of the quartz veinlets contain interstitial sericite flakes oriented parallel to the walls. This oriented sericite is contemporaneous with vein-quartz, which suggests a transition from early sericitization to the stage of vein-quartz deposition.

Champaign Mine.—The Champaign is a silver mine located in the pre-Cambrian rocks of North Mosquito Gulch. The value of the production from it has been less than from the Orphan Boy mine but considerably greater than from the Sweet Home mine. Ore shoots generally occur at the intersection of transverse fissures with the main vein, which is on a long, nearly vertical minor fault. The wall rocks of the vein are pre-Cambrian schist, granite, and pegmatite. The veins contain, in addition to supergene minerals, quartz, pyrite, sphalerite, galena, chalcopyrite, a sulpho-salt of silver, tetrahedrite, and remnants of the country rock.

Although no porphyry adjoins the vein in any of the mine workings, the wall-rock alteration is described in order to show that early sericitization of all susceptible rocks is a constant feature of vein deposition in the district. Except for small quantities of muscovite, the mineral composition of the granite away from the vein is the same as near the Sweet Home vein. In and immediately adjoining the veins, plagioclase and biotite are almost completely converted to sericite, whereas quartz, orthoclase, microcline, and muscovite have suffered little change. The texture of the granite is fairly well preserved except where it was sheared by movement along the fault. The quartz biotite schist, likewise, retains its schistose texture, although biotite was converted to sericite. In this mine, as in the others, there is abundant evidence of early vein-quartz corroding and transecting the highly sericitized rock.

Other Mines.—Many other examples of sericitization along veins could be cited, but those given are sufficient for the purpose intended. There remains, however, another class of deposits which in the Alma district are not accompanied by apparent sericitization. These are the silver-lead replacements in limestone, which do not have igneous or metamorphic wall-rocks and which are a marginal facies in the zonal arrangement of ores in each of the areas of principal mineralization.

Conclusions Regarding Local Alteration.—In the above examples, early White porphyry, quartz monzonite porphyry, pre-

Cambrian granite, and quartz-mica schist all show intense sericitization in the immediate vicinity of veins. It is reasonable to infer, therefore, that the other porphyries would show similar alteration were they adjacent to veins in mine workings. The sericitization took place as an early phase of ore deposition. Where it was most intense the end products are quartz, sericite, and insignificant amounts of accessory minerals, but with decreasing intensity there appear subordinate amounts of white carbonate accompanied, in the former ferromagnesian constituents, by minor amounts of residual leucoxene (?) and ferruginous carbonate. Where the alteration was still less intense, most of the potash feldspar remained unreplaced.

The sericitized rocks grade through distances of a few feet to several hundred feet into normal country rocks, among which the porphyries have undergone an earlier, end-phase alteration although the other rocks have been virtually unaltered. The most intense local wall-rock alteration in the district took place at the London mine, where also the richest and most extensive veins in the district are located; at other mines the intensity varies in general with the size and value of the associated veins. Thus, the relative activity of the ore solutions did not change very much during the entire period of ore deposition at any one locality. The slight alteration of quartzite and shale adjacent to veins may be attributed to the fact that these rocks are composed predominantly of one or the other of the two end products, quartz and sericite, and therefore were nearly in equilibrium with the solutions. The local alteration, like the end-phase alteration, was a selective process, so that plagioclase and ferromagnesian constituents were readily replaced, potash feldspar less readily, and quartz hardly at all; but at any one locality the same mineral has undergone the same amount of alteration in all the rocks, a condition quite different from that produced by the end-phase alterations.

SUMMARY.

Among the wall rocks of many mesothermal veins in the Alma district there are five different porphyries that during early Ter-

tiary time were erupted in a partly overlapping sequence. Their original compositions ranged from monzonitic-diorite to felsic quartz monzonite or granite. As an end-phase of its intrusion, each porphyry underwent widespread hydrothermal alteration produced by solutions that did not appreciably affect the surrounding rocks. The intensity of alteration in each porphyry depended mainly on the wetness of the particular magma, which in turn depended on the relative concentration of silica and the alkalis. The intensity did not directly depend on: (1) the percentage of easily altered minerals, (2) relative age, (3) the composition of the enclosing rock, (4) the extent of jointing, or (5) proximity to structures that localized the ore-solutions. The process of alteration, however, was selective, each original mineral developing its own secondary products; the relative ease of alteration of the constituent minerals was in the order: plagioclase and ferromagnesian constituents (readily altered), potash feldspar, quartz. The character of the end-phase alteration ranges from a chlorite-sericite-carbonate-epidote facies, where moderate, to a sericite-carbonate-albite facies, where intense.

During the first stage of ore deposition, the ore solutions intensely sericitized all susceptible wall rocks for distances of a few to several hundred feet from the veins, the exact distance depending in a general way on the size and value of the associated veins. This sericitization in the porphyries was superimposed on the earlier, widespread end-phase alteration, into which it grades. The local sericitization, like the end-phase alteration, was essentially a process of selective replacement of individual minerals, and at any one locality the same mineral has undergone essentially the same amount of alteration in all the rocks. Rocks like quartzite and shale generally show relatively little alteration because they contained almost no minerals that could be easily replaced. The end products of the most intense local alteration are quartz and sericite, but white carbonate and residual minerals that are more easily replaced than quartz appear in progressively greater abundance as the intensity diminishes.

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RIFT, GRAIN, AND HARDWAY IN SOME PRE-CAMBRIAN GRANITES, QUEBEC.[1]

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Abstract. The rift, grain, and hardway are planes approximately at right angles to one another along which granites fail most easily under tension. The rift is due to the peculiar properties of quartz and is approximately horizontal in most "Laurentian" granites. The grain is in the direction of foliation. The hardway may be a direction at right angles to the other two or may be determined by tectonic cracks or other features. The joints tend to be more consistent in attitudes than the cleavage.

INTRODUCTION.

THE commercial value of a granite depends on many factors: some of these are color (including what the quarrymen call mixture, *i.e.*, the arrangement of the contrastingly-colored constituents in the rock), granularity, accessibility to market, ease of dressing and finishing the stone, the facility of the cleavage, and the spacing of the joints as well as their relationship to the direction of cleavage and the exposed face of the stone. The cost of quarrying is governed largely by the cleavage and the joints.

Despite their importance in determining possible utilization of granites, the *cleavage planes*,[2] rift, grain, and hardway, have not received the attention they deserve in textbooks dealing with building and monument stone, some of which contain quite erroneous statements. Nevertheless, cleavage planes are the result of textures amenable to geological observation. It is the purpose of this paper to present my conclusions, based on more than eight months' field work in 1932 and 1933, concerning the origin of

[1] Published with the permission of the Director of the Quebec Bureau of Mines.

[2] The rift and grain, and in some places hardway, resemble the cleavages of minerals in that they are not actual but potential planes of separation, and there are many of them, but not an infinite number, parallel to one another. The joint planes are like the parting planes of minerals in that there are a restricted number, and they are actual planes of separation.

the cleavage directions in granites in the Laurentian area of Quebec.

Definitions.—Granite is broken in the quarry by subjecting it to tension. Blasting with black powder, the use of wedge-and-feather or of the bull-wedge, or the mere breaking of the stone to a "traced" line with a heavy hammer, are all methods of applying tension to the stone along a definite plane. Rift, grain, and hardway [3] are quarrymen's terms for the planes, approximately at right angles to one another, along which the stone fails under tension most readily, with a medium ease, and with the most difficulty, respectively (Fig. 2). The cleavages as defined above do not, however, influence directly the ease with which the stone may be drilled with a percussion drill, or broached. Because the cleavages are planes along which failure by tension is the governing factor, cracks in the minerals of the rock—either true mineral cleavages or cracks developed in other ways—are especially important in defining them; and this conclusion is borne out by the fact that the principal cleavages are parallel to prominent planes of fracturing, or cleavage, in the quartz or other minerals of the rock.

A number of explanations have been offered for the origin of cleavages in granites.[4] It is unnecessary to review such explanations here, since textures that determine the cleavages appear to be different in different places.

THE RIFT.

The rift is the plane along which the stone cleaves with the greatest ease. In most granites the direction of the rift can be determined by inspection of a hand specimen or a somewhat weathered outcrop, but in a few places it is necessary to test the direction. This is done best by blasting a single unreamed hole with black powder in a block equally free on all sides. Usually, however, it is only necessary to break this rock with a sledge or other hammer. In either case, the plane in which the stone breaks most readily is the rift.

[3] Other terms are used in some districts.

[4] Authors of important papers on the subject include Hirschwald, Parks, Stiny, Dale, Tarr, Whittle, Balk.

In most of the granites and related quartzose rocks of the pre-Cambrian area in Quebec, the rift is approximately horizontal; dips as steep as 20° are rare. However, vertical rift is found in one or two places under certain circumstances. The dip of the plane of the rift tends to be in same direction as the topographic slope and, like the slope of the water table, is less than the topographic slope. This relationship is one of considerable practical importance; most of the quarries are on hillsides, and since the rift slopes with the hill, surfaces broken on the rift drain toward the front of the quarry.

The rift is due to parallel cracks in the quartz of the rocks. These cracks tend to extend into the other constituents. The more numerous they are, the better the rift. As a rule, it is found that the higher the proportion of quartz and the coarser the granularity of the rock, the more noticeable are the cracks and the better the rift. If the amount of quartz is less than about 10 per cent, cracks may be present but not sufficiently numerous or continuous to give a good rift. The quartz of quartz veins or pegmatite dykes that cut the granite may show fractures parallel to the rift cracks in the adjacent granite. In fact, quartz veins in some fine-grained granites afford the best method of determining the direction of rift in the stone containing them. It is possible to determine accurately [5] the attitude of the fractures in such veins.

In the Laurentian area, the rift is commonly better in stone on hillsides than in that on the flat parts of hilltops or on valley bottoms; in a quarry, it may be poorer at depth than at or near the surface. In fact, in some places the rift is good only in the surface layers, so that only the outer 20 or 30 feet of the stone is removed in quarrying.

The rift cracks are easily seen in thin sections of the rock, provided the specimen is cut more or less normal to the rift. A

[5] A mirror—*e.g.* the lid of a Brunton compass—may be held near the quartz vein and turned until the observer sees the reflection of the sun in the mirror, and from the approximately plane surfaces of the cracks in the quartz, at the same time. The mirror and the rift plane are then parallel. For convenience and greater accuracy in determining the strike and dip, the mirror may be held in contact with a book or other plane surface.

section made from a chance chip of the rock, however, will not usually show them, since the tendency is for the rock to break parallel to the rift and, therefore, also to the cracks. The irregular lines of fluid inclusions sometimes seen in the quartz tend to be parallel to the rift cracks, and some workers have attributed the rift to planes rich in such inclusions. However, planes rich in fluid inclusions also trend in other directions; they appear to be of tectonic origin, similar to some tectonic fractures in quartz.

Origin of the Rift.—From the data presented above, it is fairly safe to conclude that the rift is due to the presence of quartz in the granite and is related to the topography.

It happens that some of the physical properties of quartz are decidedly different from those of other abundant constituents in granite, and the differences may account for the formation of rift cracks. The cubic compressibility of quartz, in parts per million per metric atmosphere, is 2.70, whereas for microcline and oligoclase it is 1.90 and 1.74 respectively. In most granites and syenites, the dark minerals, which have a lower coefficient of compressibility than the feldspars, are subordinate constituents. There is a similar disparity in the values for the coefficient of thermal expansion of quartz and the feldspars, and again that of the former is the higher.

In some places the rift becomes rapidly poorer downward, but the pressure differences due to load of rock in the short distances concerned are relatively small. It would seem, therefore, that the rift cracks are not due to pressure but were probably developed as a result of changes in temperature in the shell close to the surface. That they have developed parallel to the surface is no doubt due to a combination of causes. Heat conduction is slow and extends inward from the surface at an approximately uniform rate, and near the surface the load of overlying material would restrict upward expansion. It is well known that syenite is more resistant than granite to strains set up at an elevated temperature; its constituents tend to expand at more nearly the same rate than do those of granite, and the latter is consequently more easily disrupted by the differential expansion. Hence horizontal rift cracks are not likely to be developed in a syenite or other

quartzless rock. However, in spite of its tendency to easier disruption—and hence its lesser strength—granite is more sought after as a building stone on account of the rift, which facilitates quarrying.

The planes of fluid inclusions, which tend to be parallel to the rift cracks, are probably formed at greater depth than the rift cracks and may be due to removal of superincumbent granite. As the load is decreased, the granite which was formed at considerable depth under heavy load tends to extend itself in a vertical direction, *i.e.*, toward the surface, and the horizontal plane then becomes a direction of effective tension. It is noteworthy that planes of fluid inclusions normal to the direction of effective tension are developed in quartzites of a low grade of regional metamorphism. Both rift cracks and fluid inclusions are, therefore, related to the surface of the granite, the one due to the unloading and the other to the differential thermal expansion. If these hypotheses are correct, the inclusions in the quartz originate at a greater depth than the rift cracks and should lie in planes that are more nearly horizontal over a considerable area. This was not tested in the field. Fluid inclusions have been found in granites in mine workings at distance below the surface. It is doubtful if true rift cracks could be formed at depths of several hundred feet. However, cracks due to the blasting might be expected in specimens from deep mine workings.

THE GRAIN.

The grain is the plane, approximately at right angles to the rift, along which the stone breaks with an ease next to that of the rift. A most succinct statement of the nature of the grain was given me by a quarryman when I asked what he called the grain. He said, " The grain is like the grain in wood. You can see it." He referred to the plane-parallel arrangement of the inequidimensional crystals, which is commonly in the direction of the grain. In some rocks devoid of quartz, such as syenites, gabbros, and anorthosites, this plane of " foliation " is in the direction of most easy breaking, and it is therefore the rift. Similarly, in a rock low in quartz, the true rift due to the cracks in the quartz might

become poorer with depth, and the grain would then become the rift. In the quartzless gneisses the rift is in the foliation, and in some microbreccias derived from granite, the quartz has been reduced to small size and the rift is in the plane of the shear. The essexite of Mount Johnson rifts parallel to the vertical fluidal arrangement. The syenite gneiss (granulite) of Chicoutimi has the same direction of foliation as the grain, but here a cracking extends through all the constituents, apparently due to tectonic conditions since it parallels the course of the Saguenay river and dies out at a distance from the river. These cracks are less closely spaced than the rift cracks of a normal granite, and the rift is consequently poorer. In one quarry in a coarse granite at Rivière à Pierre, the hardway is parallel to the foliation. This is an exceptional arrangement and is due to a fracturing of the quartz similar to but less perfect than the normal rift cracking. It is parallel to an adjacent valley and is the direction of the grain. These cracks are apparently also of tectonic origin and, as at Chicoutimi, they become less marked in the rock in quarries farther from the valley. In most granites, however, the grain is the direction of the foliation. In some places the stone is worked at an angle to the true grain in order to get rectangular blocks, perhaps on account of the attitude of the rift or of prominent joints.

The inequidimensional constituents of granite are feldspar and mica. The (010) cleavage of feldspar and (001) cleavage of mica determine the grain. A foliation of this type is almost universal in the granites of the pre-Cambrian but is hardly noticeable in some massive-appearing granites, as for example, the well-known Baveno granite. In such cases it is difficult to determine the direction of grain. In some places a linear parallel arrangement of constituents is found superimposed on the plane-parallel arrangement, or a linear parallel arrangement is found alone. I know of no quarry in Quebec in which the granite has the linear arrangement alone.

It has been mentioned (under Rift) that chips broken from granite tend to be parallel to the rift—that is, parallel to the cracks in the quartz grains. As a corollary, then, in a grain section most

of the feldspar will be broken in a zone whose axis is *b*. This expectation is confirmed by observation of thin sections. In the case of some granites, a linear parallel arrangement of the constituents is seen in thin sections of the rock but not in the hand specimens. The blue-gray granite of Rivière à Pierre in thin sections cut parallel to the (vertical) hardway shows rift cracks and foliation, and the large grains of plagioclase (An28) all show nearly central emergence of α, indicating a vertical linear parallel arrangement of the feldspar.

The grain tends to be parallel to the nearest contact of the granite with an older formation. This, however, is a tendency only. If the strikes of the foliation over a wide area are plotted, considerable deviation from parallelism is seen. This is shown in the edge of the massif of coarse-granular granite at Rivierè à Pierre (Fig. 1). Here, instead of being haphazard, there is a grouping in the variations in strike of foliation, suggesting the formation of eddies in the crystal "mush." Similar observations were made in other places.

THE HARDWAY.

The hardway is the plane, approximately at right angles to both rift and grain, in which the stone breaks with greater difficulty than in the other two planes. The hardway may be a random direction determined by the attitude of the other two cleavages or it may be controlled by a tectonic cracking less well developed than the rift cracking or other feature of the rock.

COMPARISON OF THE DIRECTIONS.

The broken rift surface is flatter than the other two and smoother to the feel. The hardway surface tends to be tuberculate, due to the intersection of flat conchoidal fractures, and is sharper to the feel than the other two. The grain surface has characters intermediate between the other two.

The hardway face is the one ordinarily polished; it shows the most even texture, and moreover, the impression is general that it takes a better polish than any other surface. In the case of

stone with much dark mineral and marked foliation, the polished grain face is much darker in tone than the other two faces. The rift face of some fine-grained granites appears to be of slightly coarser grain than the average for the rock.

Not only is the tensile strength of a stone different in the three

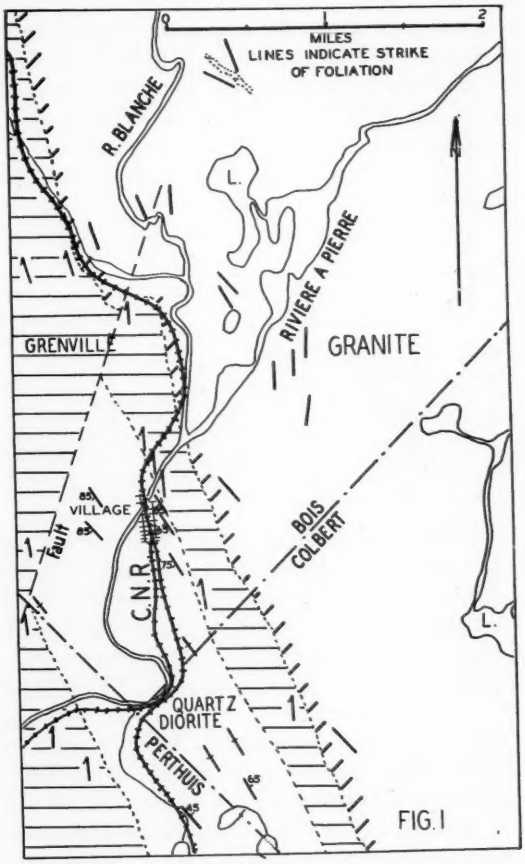

FIG. 1. Granite massifs, Rivière à Pierre, showing direction of foliation. (Courtesy of Amer. Journal of Science.)

cleavage directions, but the method of testing the compressive strength allows the cleavages to influence the results considerably. These differences are well illustrated in a series of tests of specimens collected by F. R. Burton and L. H. Cole [6] from quarries in Quebec. The cubes were prepared and tested under the supervision of Burton. Three specimens parallel to each cleavage direction—nine specimens from each rock—were tested in compression between the prepared faces on two-inch cubes. The results are consistent and show that the stone is strongest when the stress is applied to the rift, of intermediate strength parallel to the grain, and weakest when compressed on the hardway. The following table gives the arithmetical mean of three determinations parallel to each direction for the seven granites tested, arranged in order of greatest, intermediate, and least strength.

FAILING LOAD POUNDS PER SQ. IN.

	Greatest.	Intermediate.	Least.
A	23,295	23,200	19,770
B	27,840	26,500	26,390
C	29,630	26,310	25,680
D	30,990	29,600	27,605
E	28,660	26,890	25,000
F	28,590	26,800	22,590
G	27,650	24,625	18,753

For most of the specimens the greatest strength is normal to the rift, and the least is normal to the hardway. Absolute consistency of results was not obtained, but it is believed this was due to the fact that on some of the specimens the faces of a set of cubes were inadvertently mislabelled. This was afterwards recognized as being true for at least two sets. The explanation of the lesser compressive strength normal to the hardway is not difficult: when the blocks are placed in the compression machine they are unsupported laterally and the horizontal directions then become directions of effective tension. The cleavage directions, being weak in tension, cause the rock to fail at a lower load than they otherwise might. When the rift and grain faces are un-

[6] Quebec Bureau of Mines, Ann. Rept. 1931, Part E.

supported, *i.e.*, when the pressure is applied on the hardway, the stone is weakest. The fact that it is the cleavage that causes the failure under compression may explain why the strength of the granite is increased if it is supported laterally, as by an enclosing steel or copper jacket, when it is being compressed. It is interesting to observe that the essexite of Mount Johnson, which consists largely of plagioclase, a cleavable mineral, has a compressive strength normal to the rift (foliation) of nearly 41,000 pounds—considerably greater than that of any of the granites listed above.

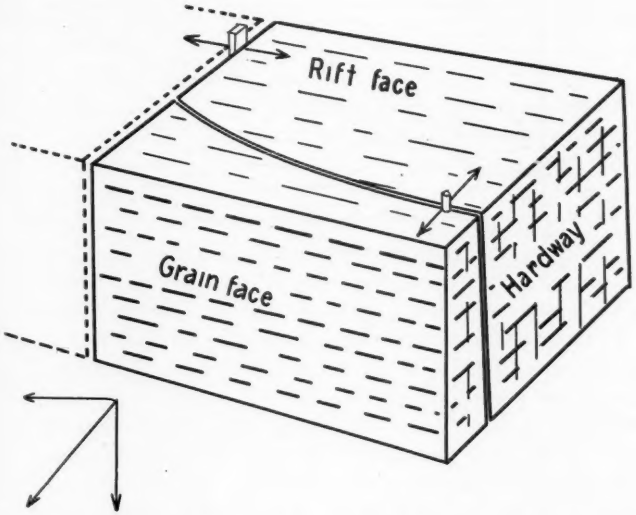

FIG. 2. Block of granite bounded by cleavage faces, showing how break parallel to rift tends to turn in direction of wedge, causing pressure on hardway.

Peculiarity of the Quarry Directions.—It is an important fact that a granite may be broken at a small angle to the rift or the grain with greater ease than in a random direction. In some quarries the stone is broken in such directions on account of the attitude of joints, and in a few places because the quarrymen have

not taken the trouble to ascertain the proper cleavage directions. Some granites will break only along the true rift when they are frozen or at very low temperature. Some stones break much more easily in all directions when they are frozen, whereas the reverse is true of others.

If the stone is broken at an angle to the rift, the break may be seen to be stepped, *i.e.*, the flat rift fractures are joined by inclined fractures. This is shown in Fig. 3. The same is true if the stone is broken at a small angle to the grain.

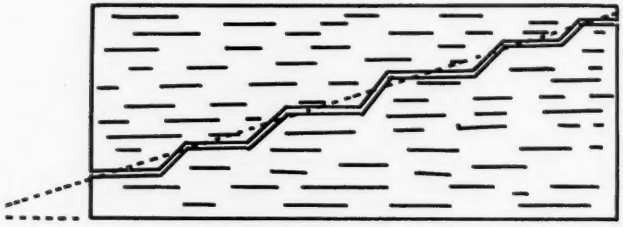

FIG. 3. Diagrammatic sketch of compromise break. Direction of cleavage indicated by dashes.

It is sometimes mentioned as a peculiarity of the rift or grain that a break tends to deviate from the cleavage direction if the stone is not free on the end or side. Fig. 2 shows the relationship most commonly met in quarrying. The wedge on the broken end may represent the end of a lever or even another block of stone pressing against the end. The break will turn toward such a place where pressure is applied. This is easily seen if a polygon of forces is prepared showing the direction of the components. The break tends to be normal to the tension. The force exerted on the end tends to make the stone break with the formation of a compromise surface.

Relationship to the Jointing.—The joints are quite separate and distinct from the cleavage directions. In theory the least loss in quarrying is involved if the three cleavage planes are the directions of the principal joints. This is true if the granite is equally accessible on all sides. In practice, however, this arrangement

may not be satisfactory, but use is made of joints inclined to the cleavage directions, especially if two joints converge ahead of the working face. Such "in-going" joints may allow the stone to be opened along the grain or rift and the face advanced with the least work. The spacing of the joints is important; if they are widely spaced much actual breaking of the stone is necessary; if they are too closely spaced it may not be possible to quarry stone of commercial dimensions.

In many quarries, there is a well-developed direction of jointing parallel to the hardway (Cloos, Q joints). In most places the other joints are inclined to the cleavage. If the attitude of joints is plotted for a considerable area and compared with that of the grain, it will be found that the joints are more constant in strike than the grain. This is explained by the fact that the foliation is developed during the late magmatic stages, and the jointing after the rock is entirely solid. The sheet-joints have long been recognized as a result of weathering. They tend to be lenticular and are commonly somewhat less flat in dip than the rift. In some quarries the sheet joints are spaced at considerable intervals and the stone is opened in artificial sheets along the rift by blasting with black powder. Some otherwise good commercial granites are not utilized because of the absence of sheet joints.

McGill University,
Montreal, Quebec,
Oct. 10, 1934.

STAINING MINERALS FOR EASIER IDENTIFICATION IN QUANTITATIVE MINERAGRAPHIC PROBLEMS.[1]

A. M. GAUDIN.

IN THE course of quantitative mineragraphic studies made of mill products, and more especially of flotation concentrates and tailings, the need was felt for means of identifying minerals instantly, merely by their color. In quantitative mineragraphic studies it is essential to extend the investigation to a number of particles large enough to minimize the error inherent in the sampling involved. In order, therefore, to make such studies practical, the technique of viewing the sample, identifying the mineral or minerals in each particle, and recording the results, must be made as simple as possible. All the operations involved can be mechanized sufficiently to meet the requirement, provided identification of the mineral can be made unequivocal and practically instantaneous, requiring perhaps not more than two or three seconds of inspection, per particle studied.

With this end in view, the literature of mineragraphy has been combed for possible "recipes" for producing differential stains on mineral particles having the same color or otherwise not readily distinguishable under the microscope. This search made obvious the difference in viewpoint of the average mineralogist and the one engaged in a problem of quantitative mineragraphy, since to the former staining is of value only in doubtful cases. As a result of these requirements, the mineralogist's technique has grown to consist in placing drops on a polished surface, examining the wet surface for etch reactions, and finally wiping the drop, and rubbing the surface.

Several objections must be raised to this technique: (1) It precludes the use of high-power objectives, where the short work-

[1] Contribution from the Ore-Dressing Laboratories of the Montana School of Mines.

ing distance makes it difficult not to attack the metal in the lens-mounting with the chemicals used; (2) differences in rate of staining occur at the center and edges of the drop, and the operation must be conducted without temperature control and frequently without timing; (3) capillary openings in the surface tested may cause the testing fluid to remain within the specimen unsuspected, and subsequently cause undesirable stains.

From the standpoint of quantitative mineragraphy, and without prejudice to the customary method of dealing with the preliminary stages of mineral identification, it would seem that a suitable method should involve: (1) Even change of appearance through the whole of the specimen by immersion of all the specimen at once in the testing fluid; (2) washing the specimen, and drying it without permitting the formation of "drying" deposits; (3) the securing of known, reproducible, and characteristic results with air- and oil-immersion lenses alike.

It is interesting to note how little attention has been paid to the mechanism by which surfaces become changed in appearance through the use of sundry chemical agents. The terms etching and staining are sometimes used indiscriminately in this connection.

There seem to be three principal methods by which the appearance of a mineral surface becomes changed. These are: (1) Dissolution of part of the surface; (2) precipitation on the surface of a coating differing in color from the mineral treated; (3) formation of transparent coatings that acquire interference colors.

Combination of these three principal methods may occur and thus afford a wider variety of technique to the microscopist.

DISSOLUTION OF PART OF THE SURFACE.

This favorite method for developing structure in polished surfaces does not, of course, produce changes in color, except for a selective darkening of the mineral or minerals that are dissolved. For instance, the differentiation between enargite and the gray coppers by treatment with an aqueous cyanide solution is an extreme example of what can be done by this method. It is

especially valuable for bringing out structural features in anisotropic minerals, although it can also be used to develop those features in isotropic minerals, *e.g.* in chalcocite or bornite.

As a practical tool in quantitative mineragraphy, the method must be set aside because the particles studied are generally so small that the desired structural features are not brought out: some suitably oriented particles become entirely etched away while others are unaffected.

PRECIPITATION OF COATING DIFFERING IN COLOR FROM THE SUBSTRATUM.

This method has apparently failed to receive the attention it deserves. It has possibilities much wider than those of the dissolution method, not only in the examination of polished surfaces, but more especially in the examination of loose grains with petrographic or oblique-illumination (*e.g.* "ultropak") microscopes. A typical example is afforded by the differentiation of quartz from calcite (as loose grains). These minerals should be readily differentiated by their difference in refractive index, and by the presence of cleavage in calcite. Yet both of these criteria may fail: a coarser quartz grain and a finer calcite grain may give similar interference colors, especially in suitable orientations; a locked particle consisting of calcite and quartz would be very embarassing. But calcite can be stained in a variety of ways to suit the requirements of almost any problem: boiled with ferric chloride, it acquires a yellow to brown coat of ferric hydroxide; with nickel nitrate, a green coat of nickel hydroxide; with silver nitrate, a brown to black coat of silver oxide. At the same time quartz is unaffected by any of these agents.

The coatings that may be applied to the widest variety of minerals include the products of simple chemical (metathetical) reaction, of adsorption followed by chemical reaction, and of more complex reactions. The following examples are illustrative.

1. Potassium chromate colors anglesite yellow:

$$PbSO_4 + CrO_4^{--} \rightarrow PbCrO_4 + SO_4^{--}.$$

2. The dye known as malachite green colors hydrous oxides.

If the mineral is colorless, the coating is blue; if the mineral is colored, the coated mineral appears intermediate in color between blue and the color of the substratum. Anhydrous oxides do not react. Compare, for example, limonite and hematite, or bauxite and corundum. The action seems to be specific for minerals with hydroxyl radicals. It is not known whether the action involves exchange between the hydroxyl radical and the organic dye radical, but it has been ascertained that fixation of the organic radical on the hydrous mineral is involved. Similar reactions occur with organic dyes other than malachite green.

3. Galena reacts with copper sulphate to yield a complex coating of cupric sulphide and lead sulphate:

$$PbS + Cu^{++} + SO_4^{--} \rightarrow PbSO_4\downarrow + CuS\downarrow.$$

These reactions can be controlled by a variety of factors to which thus far too little attention has been paid. These factors include: (*a*) temperature of bath; (*b*) duration of reaction; (*c*) agitation of solution during reaction; (*d*) pH of bath (acidity or alkalinity); (*e*) choice of suitable method for drying after staining.

The following example shows the importance of one of these factors: In acid chromate solutions (= dichromate) lead carbonate is stained yellow in preference to lead sulphate, but in alkaline or neutral chromate solutions (= chromate) lead sulphate is stained in preference to lead carbonate. This is no doubt related to the relative solubilities of the minerals at the various degrees of acidity or alkalinity used.

The technique of the method can be elaborated to make use of successive formations of two coatings, *e.g.*: To differentiate between quartz and barite in short order so as to control a flotation concentrating operation. While the machine was running at reduced speed, a small sample of the froth was deslimed crudely, and boiled for a few minutes with an excess of sodium carbonate. This changed the surface of the barite to barium carbonate ($BaSO_4 + CO_3^{--} \rightarrow BaCO_3\downarrow + SO_4^{--}$). The mineral was then washed and warmed with potassium chromate, which changed the barium carbonate to yellow barium chromate

$$(BaCO_3 + CrO_4^{--} \rightarrow BaCrO_4\uparrow + CO_3^{--}).$$

The first operation could not be omitted, since potassium chromate apparently does not react sufficiently with barium sulphate. The quartz remained unchanged throughout the staining operation.

Again, the method need not be restricted to operations involving an aqueous solution. No doubt some stains can be developed with non-aqueous solutions, also by operations involving the atmosphere as a fluid. Thus, a mixture of manganese carbonate and silicates can be modified so as to permit instant identification by submitting the mixture to a low-temperature roast which changes manganese carbonate to the black dioxide

$$(MnCO_3 \rightarrow MnO + \uparrow CO_2;\ MnO + \tfrac{1}{2}O_2 \rightarrow \downarrow MnO_2).$$

FORMATION OF TRANSPARENT COATINGS DISPLAYING INTERFERENCE COLORS.

This method seems to have the most promise of all for the study of sulphide minerals in polished sections. It is extremely flexible, and so susceptible to variation under modifying conditions that it has been regarded as extremely unreliable by those who used it accidentally. If suitably applied, however, it is most useful, and yields polished surfaces with brilliant and easily recognized colors. It is preferable to polarized reflecting light because it is usable at all magnifications. The beautiful results obtained might incline one to predict that it will do for the student of polished surfaces what the use of polarized light has done for the student of thin sections; but such conclusions, tempting as they are, need further study for their justification.

Briefly speaking, the principle of the method seems to be as follows: When light falls on a coated surface having a transparent coat, light is reflected both from the surface of the coat and from the surface of the substratum. If monochromatic light is used, and the two reflected beams are in phase, an intense color will be noted, that of the light used, of course; if the beams are in opposition, a faint color only will be seen, unless the two reflected beams have the same intensity; in that case the surface will appear devoid of color (black). With white light consisting

of all the wave-lengths of the visible spectrum, some wave-lengths will be missing or reduced in intensity in the compound reflected beam and the surface will appear colored.

Thus, to get a film of a color corresponding to wave-length λ, that is, one in which the reflected beams of wave-length λ are in phase, the film should have a thickness θ such that $2\theta = \lambda$. In the case of blue light ($\lambda = 0.5\ \mu$), θ must equal $0.25\ \mu$.

Clearly the films will evolve in the order: violet, blue, green, yellow, orange, red, after which a second order of interference colors may appear in which the two reflected beams that give the color to the surface differ by two phases.

The principle of the method, as outlined here, is predicated on the following assumptions: (*a*) reflection at the top and bottom of the coating film is of a commensurate order of magnitude; (*b*) the coating is transparent; (*c*) the substratum is substantially plane; (*d*) the coating is colorless; (*e*) the substratum reflects all wave-lengths to approximately the same extent (appears white or gray when not stained).

If any one or any combination of these assumptions is not realized, the range of the spectrum observable in the treated surface will be limited in proportion to the amount of deviation from the theoretical assumptions just listed. But these deviations and limitations, far from being objectionable, are the very life and value of the method, since they are characteristic of the various surfaces and the coatings obtained on them. As a result, under a given set of film-forming conditions, minerals A, B, C, . . . Z will differ not only in the *rate* at which the film is formed, but also in the *character* and *intensity* of the modifying factor or factors available.

Formation of the Coating.—Of the various methods that could be devised for forming a transparent coating displaying interference colors on sulphide minerals, one of the most satisfactory seems to be oxidation. It is well known that sulphides oxidize slowly, which insures the formation of thin films; furthermore, most oxides of the metals that are found currently as sulphides are light-colored and reasonably transparent.

There are a variety of oxidizing agents. For example, iodine

in aqueous potassium iodide, chromic acid, chromic acid in sulphuric acid, chlorine, bromine, sodium peroxide, hydrogen peroxide, potassium chlorate, nitric acid, etc. Some of these are no doubt too weak; others will be too strong unless suitably diluted; but in a fairly complete list of oxidizing agents, will be found a number suitable for particular purposes,—agents that will stain some minerals but fail to stain others, and the action of which will be selective as to the color produced.

The principal variables involved in connection with the precipitation of colored coatings appear to be: (*a*) concentration of each ingredient in the staining medium; (*b*) temperature of bath; (*c*) duration of reaction; (*d*) agitation of solution during reaction; (*e*) pH of bath (alkalinity or acidity); (*f*) drying of stained specimen; (*g*) state of "conditioning" of solution.

The last variable may appear somewhat confusing: it was observed repeatedly that much better results were obtained from "aged" or "conditioned" solutions than from fresh solutions. No doubt some reaction within the staining bath causes improvement through aging but thus far the cause remains unidentified.

One of the difficulties inherent in the method is that anisotropic minerals behave differently in different directions. In the case of these minerals it is desirable to choose a staining agent having only a limited range of color, so as to minimize variations due to cutting crystals in different directions. The same may be true, although to a vastly lesser degree, with isotropic minerals. Generally speaking, it is best to seek modifying agents that cause anisotropic minerals to remain unchanged.

Practical Application.—It has been found most convenient to apply the stain as follows: The mineral is first mounted in bakelite and polished. The specimen is then immersed in the proper solution in a small beaker or dish, kept at the proper temperature on a water-bath, and timed accurately with a stopwatch. The specimen is then withdrawn with non-corrosive forceps, washed under running water, then in a small stream of ethanol, and finally in a stream of diethyl ether, before drying by a fan or by waving

in the air. The stained surface is mounted on plasticene ready for use. It is desirable that the surface be free of pores and be polished without relief. Most stained surfaces change color in time, due to further oxidation and to re-arrangement of the substances in the coating. They should therefore be used promptly after preparation.

Examples from Practice.—The following examples from practice illustrate what can be done by way of differentiating between minerals by staining with one typical solution.[2] The solution was made as follows: One part of chromic oxide (CrO_3) was first mixed with five parts of water; two parts of this solution was mixed with three parts of concentrated hydrochloric acid; the mixture was diluted with water in the proportion of one to two, and aged for at least one-half hour before use. The resulting mixture had thus been made from 70 parts water, 18 parts concentrated hydrochloric acid and two parts chromic oxide.

Polished pentlandite exposed to this solution for five to six minutes at 62° F. becomes brilliant blue in color; chalcopyrite is not changed in color and pyrrhotite is darkened to a duller, darker bronze. These minerals are commonly associated in the Sudbury district. The method used differentiates so clearly between the minerals that eutectoid structures of pentlandite and pyrrhotite in which the leaflets of minerals are 1 to 2 μ thick can be identified instantaneously.

It is interesting to note that the pentlandite changes first from the cream color of the unstained surface to purple, then blue, blue-green, green-yellow, and straw. This sequence of changes corresponds to staining times of 4, 5.5, 6, 7, and 8.5 minutes, approximately. It was observed that an increase in temperature causes more rapid reaction.

If the reaction period is too long, marked color changes appear in the pyrrhotite, the color changing first to purple, then to blue, green and yellow. In contrast to the uniform color of the pentlandite, it should be noted that the color of the stained pyrrhotite is characteristically non-uniform, some grains appearing purple,

[2] Devised by H. B. Henderson, Montana School of Mines.

some green, and others, yellow. This certainly must be related to the isotropic properties of pentlandite and the anisotropic properties of pyrrhotite.

With a more concentrated staining solution, chalcopyrite can be induced to take on all the colors of the rainbow. Pseudomassive chalcopyrite is resolved by this method to an aggregate of crystals, commonly twinned, recalling the structure of alpha brass. This, although of no practical use in differentiating between minerals, as it adds to the natural confusion of colors, has value from a structural standpoint.

Neither pyrite, nor arsenopyrite, nor sphalerite are stained under the normal analytical staining conditions stated above, but galena becomes covered by a thick crust of dull yellow lead chromate.

To summarize, under normal conditions (5 to 6 minute stain, with solution as stated above, at 62° F.) the various minerals appear as follows:

chalcopyrite	brass-yellow
pentlandite	brilliant blue
pyrrhotite	dark bronze
pyrite	unchanged
arsenopyrite	unchanged
galena	very dull yellow.

When viewed under oil-immersion, the blue color of the stained pentlandite is changed to a pale lavender which is characteristic, although not so sharply in contrast with the color of associated minerals as is the blue color observed with air-immersion objectives.

The same solution as that used to differentiate between pentlandite and pyrrhotite can be used to differentiate between tetrahedrite, tennantite and enargite. A reaction time of 4 to 5 minutes at 62 to 65° F. produces the following colors:

enargite	unchanged
tetrahedrite	buff
tennantite	blue-green

Solid solutions of tennantite in tetrahedrite exhibit colors ranging from blue-green to dull buff through apple-green, yellow-green and straw.

COMBINATION METHODS.

Under this heading are considered methods in which a colored opaque coating is formed on some minerals by metathesis, and more or less transparent iridescent coatings on other minerals. The principles involved are the same as stated above.

A typical example is offered by the action of 'conditioned' solutions of silver nitrate on some of the common sulphides. The solutions used have a concentration of 15–25 per cent. silver nitrate, and are used at a temperature of 50° to 90° C. for 15 to 3 minutes, respectively. Five-minute immersions at 65° C. with a 20 per cent. solution seem to give the best results.[3] By "conditioned" solutions is meant solutions in which a considerable number of immersions of specimens had already been made. The colors obtained are as follows:

	Air-Immersion	Oil-Immersion
Pyrrhotite	Deep greenish blue; dull luster	Purple; increased luster
Chalcopyrite	Olive green; high luster	Brilliant green; high luster
Sphalerite	White to light gray; high luster	White; high luster
Galena	Tan to buff; dull luster	Tan to buff; increased luster

In this instance the sphalerite becomes coated with argentite or with native silver, the galena, possibly with lead sulphate mixed, with native silver and silver sulphide, while the other two minerals may be merely oxidized, silver being reduced in the solution.

[3] Devised by R. A. Dawson, Montana School of Mines.

SUMMARY.

The various methods available for changing the appearance of minerals to facilitate microscopic identification are reviewed and classified. A wider use of these methods will no doubt be made, especially in quantitative mineragraphic studies.

Some examples are given which made possible the solution of some practical problems of mineragraphic analysis.

Further work is in progress.

BUTTE, MONTANA,
August, 1934.

DISCUSSION AND COMMUNICATIONS

ORIGIN OF BARITE IN THE APPALACHIAN VALLEY.

Sir: The occurrence of barite in Ordovician limestone in the Sinks district, Bibb County, Alabama, is described by W. B. Jones and T. N. McVay in the December issue of Economic Geology. The writers subscribe to the theory of hydrothermal origin, previously presented by George I. Adams.[1] Adams found barite in pre-Cambrian mica schist, in which also occur gold quartz veins of hydrothermal origin. The association of barite with argentiferous galena, sphalerite, and fluorite in Paleozoic rocks is cited by Adams as supporting evidence of hydrothermal origin. Jones and McVay also found fluorite associated with barite, but metallic sulphides are absent from the deposits in the Sinks district.

The origin of the commercial deposits of barite I do not question at this time, although it does appear that much of the evidence cited in support of the view that " the barium was brought up in emanations from magmas and deposited as veins and replacements " [2] is not at all conclusive and could be differently interpreted. It seems to me unfortunate that the detailed relationship of the various minerals to one another is not made clear either by descriptions or photographs. The impression is given by Jones and McVay, perhaps unwittingly, that all the barite originated in the manner described above. There is good evidence that such is not the case, that there are actually two generations of barite deposition, one hypogene and the other supergene. This is particularly well shown in the Cartersville district, Georgia.

[1] Adams, George I.: Hydrothermal Origin of the Barite in Alabama. Econ. Geol., vol. XXVI, pp. 772–776, 1931.

[2] *Op. cit.*, p. 776.

The Cartersville district has yielded a large proportion of the domestic production of barite. The mineral there occurs as (1) veins in lower Cambrian limestone and quartzite, and in pre-Cambrian graphitic phyllite; (2) replacement deposits in limestone; (3) breccias—limestone breccias with barite as a matrix and barite breccias with ocherous material as a matrix. Most of the barite is recovered from colluvial deposits derived from the residual disintegration of breccias and veins. The mineral from these deposits is fine-grained and has a dead white to bluish white color. It is closely associated with deposits of manganese and ocher. The formation of the barite in bed-rock, from which these surficial accumulations were derived, was followed by a period of deformation, as evidenced by the commonly brecciated condition of the mineral.

At some ocher mines, particularly the abandoned Georgia Peruvian mine, barite occurs in open cavities in quartzite that has been shattered and partly replaced by iron oxides. The crystals are noteworthy because of their size and perfection of form. Most of them have the characteristic tabular shape and some have a length of as much as 4 inches. The crystals project into the cavities at various angles to the walls, forming a delicate network. There is so striking a difference between these transparent crystals and the massive white barite that the local miners did not at first recognize their identity. The crystals were picturesquely called "flowers of ocher." Similar crystals, 2 to 3 inches in length, are reported to occur in the Sinks district of Alabama.

The fragile "flowers of ocher" could hardly survive the type of deformation that brecciated the neighboring barite veins. For this reason, it is thought that the barite in cavities was deposited after the fracturing and mineralization of the enclosing rocks, that is, after the deposition of the barite veins. It seems reasonable to suppose that the barium was derived from earlier barite deposits by the circulation of surface waters.

GEOFFREY W. CRICKMAY.

ASSISTANT STATE GEOLOGIST,
ATLANTA, GEORGIA,
Feb. 22, 1935.

THE ORE DEPOSITS OF THE TRI-STATE DISTRICT

Sir: The December, 1933, number of this journal contained an interesting discussion by our old friend Mr. Reno H. Sales, who introduced us to mining geology, regarding our paper "The Ore Deposits of the Tri-State District,"[1] which gives a brief summary of our geologic observations in this district.

On the first page of our paper we state: "A more comprehensive paper is contemplated later." It was evident to us that many of our statements would have to be amplified and we hope to do this in a later paper. We particularly desired at that time to show the relationship between structure and ore deposits and to stress the utilization of structural control in ore-finding. Structure is extremely important in the localization of ore bodies; it supplied the channelways of ingress and made many ore reservoirs.

Mr. Sales questions our interpretations regarding deformation, and doubts the importance of structure in ore-finding in the Tri-State District. However, a practical knowledge of the structure in this district has resulted in successful exploration at a minimum cost, and in the ready elimination of many areas as barren. The size, shape, and richness of every ore deposit in this district are controlled by the degree and character of structural deformation. Without deformation there would have been no ore deposits.

Mr. Sales bases his observations regarding this district upon a short visit with us in the spring of 1927; his observations were limited to less than ten per cent of the mines. In reality our studies were just starting in 1927. We realized that we had found an interesting structural problem and that its solution would be greatly simplified if we could identify the beds comprising the Boone formation throughout the district and determine the structural relations in a major unit of the district. After repeated efforts and months of study we succeeded in doing this by the latter part of 1928.

All our notes taken in 1927 were laid aside as useless because we had then failed to see or record many essential facts that later became evident only after continued study. It is extremely in-

[1] Amer. Inst. Min. Eng. Tech. Pub. 446, and Transactions, vol. 102, 1932.

teresting to compare these early meager notes with our later notes on the same areas. We now have detailed geologic data covering more than ninety-five per cent. of the mines, from which we have worked out the structural pattern of the Oklahoma-Kansas field, the richest major ore-bearing unit discovered to date in the Tri-State District, with a gross production of more than $400,000,000 since 1915.

Mr. Sales states:

> Their presentation of the geological history of these deposits is not clear with respect to the relation between the various processes of dolomitization, chertification, brecciation and later mineralization. . . . They identify the early chertification and dolomitization with a deformation of pre-Cherokee age but associate the jasper and ore mineralization with an igneous activity certainly of post-Cherokee age. . . . Fowler and Lyden do not mention the existence of the Mayes formation. In view of this longtime interval between the period of early chertification and later sulphide mineralization, it seems logical to connect the early chertification with the orogenic disturbances responsible for the folding and crumpling of the Boone formation but having no connection with post-Cherokee igneous activity.

Our observations are as Mr. Sales states in the second sentence in the preceding paragraph. We recognize a long interval between the cycles of chertification and ore deposition, as is recognized between the intrusion of the quartz porphyry dikes and the ore bodies at Butte.[2] The ore bodies of the Tri-State District follow closely the general trends of the intensive chert mineralization. Mr. Sales offers no suggestion other than the time interval to preclude a relationship between the chert and the ore bodies. The great masses of chert in this district were probably derived primarily from siliceous emanations due to igneous activity.

In the Tri-State District there were two periods of chertification, both during Mississippian times. The chert pebbles in the base of the Carterville limestone were eroded from the Boone formation and attest the age of the chert as pre-Carterville, as stated by Weidman.[3] Chertified zones of Boone limestone are

[2] Sales, Reno H.: Ore Deposits of Butte, Montana. Amer. Inst. Min. Met. Eng. Trans., vol. XLVI, p. 1529, 1914.

[3] Weidman, Samuel: The Miami-Picher Zinc-Lead District, Oklahoma. Okla. Geol. Surv. Bull. 56, 1932. University Press, Norman, Okla.

widespread throughout the district. It is impossible from present evidence to place the age of the sulphide mineralization, except to state that it is post-Pennsylvanian, as this formation contains jasperoid and ore in some zones of deformation.

Mr. Sales overlooked our reference to the Mayes formation. Near the bottom of page 12 we state: ". . . near Miami, this formation (designated as the Mayes in Oklahoma) is fairly widespread." Part of the Mayes is equivalent to the Carterville limestone and Chester series of Missouri. On page 15, under General Geologic Section, we state: "Carterville formation—sandstones, limestones, and shale. Occurs as outliers in sink holes in all parts of the district. In the extreme southern part of the district between Miami and Lincolnville, Oklahoma, this formation covers areas of several square miles." The Carterville and Mayes are equivalent to part of the Chester series, and the latter is probably the most acceptable designation.

Regarding deformation and chertification of the strata, Mr. Sales says:

> Fowler and Lyden lay much stress upon the rôle played by shattered zones, fissures, and shears as channelways through which the early chertifying solutions traveled, yet I was unable, during my examination of the Miami district, to find evidence to support that theory. The early chert shows no vertical arrangement along intersecting fissures or fissure zones. There is no replacement of wall rock along or adjacent to shears, cracks, or fissures, such as is found in typical examples in other ore deposits where mineralizing solutions travel through fissures. On the other hand, the chert is strictly conformable to the bedding of the limestone. The occurrence of the early chert in the Picher-Miami area is typical of bedded cherts I have seen elsewhere, and which appear to be the result of obscure processes of metamorphism associated with regional deformation but not necessarily related to igneous activity.

Shattered zones, fissures, and shears were not the only channelways through which the mineralizing solutions traveled. Of equal importance were the openings on bedding planes caused by deformation. In our paper we lay stress primarily upon deformation and secondarily upon the different expressions of deformation such as shattered zones, fissures, shears, flexures, and

movements on bedding planes, which are the result of deformation and not the cause. Mr. Sales did not differentiate the respective beds and ore-bearing horizons and for this reason did not have the necessary data to make structure maps and determine the relation between mineralization and deformation.

He states that: "The early chert shows no vertical arrangement along intersecting fissures or fissure zones." To determine this point it is necessary to compare the quantity of chert in the vertical fissure zones with that of surrounding areas. Definite evidence, gained from underground workings, drill hole logs, and structure maps of the district, shows intense chertification in the zones of sharp flexing and strong shearing, with a marked decrease ranging to complete absence of chertification in the beds away from these zones. The boundaries of the intensely chertified zones are irregular and were influenced by the inherent nature of the respective beds. Mr. Sales is emphatic in stating that the chert is strictly conformable to the bedding of the limestones. In a general way this is true of the respective chertified beds, and is what would be expected regardless of the manner in which the chertifying solutions reached them. In our paper we stress the point that each limestone bed has its characteristic manner of becoming chertified. It was some inherent characteristic of each limestone bed that influenced the type of chertification. The fissures or shears or other openings simply acted as channelways for the solutions. A completely chertified stratum is necessarily conformable to the general bedding of the formation, but in a partly chertified stratum the chert boundaries in the limestone are commonly irregular and therefore not always conformable. There are many instances where the long axes of chert nodules are aligned at an angle to the bedding, and greater quantities of chert are found in the respective beds vertically along shear and fissure zones than in the surrounding areas. All the chertification is definitely related to deformation. Where deformation is expressed by shearing across the beds, there are irregular vertical zones of chert. Where deformation is expressed by movement on the bedding planes, the chert is interbedded with the

limestone.[4] The processes responsible for the chertification in this district are evident; the problem of the source of the chert warrants further study. We cite the field evidence as we have observed it.

In a following paragraph (page 781), Mr. Sales attempted to tie the ore bodies to fissuring and shearing alone.

Shearing and fissuring are important but, as we stated before, deformation also resulted in flexing of the beds with attendant movement and openings on bedding planes. In this latter type of deformation, shearing and fissuring across the beds is not common except in sharp flexures. On page 24 of our initial paper we state: "There are two distinct types of regional deformation in the Boone formation, characterized by (1) flexing of the beds; (2) a series of strong shear zones. Deformation by folding caused shearing and shattering of the beds in areas of sharp flexing." And, near the bottom of page 24: "Shearing across the ore beds produced long, narrow, high ore bodies. Movement on the bedding planes is characteristic of the sheet ground type of deposit, but both types of deformation are found in the same area. Such zones are the loci of the major ore bodies in the Picher-Miami area."

On page 782, Mr. Sales states:

> Just as there is no vertical arrangement of chertification along so-called fissures or shears, similarly there are no jasper, sulphides, or any vein minerals whatsoever, arranged crosswise of the bedding along steep-dipping shears cutting the Boone. The argument that such shearing or planes of readjustment as may now be recognized within the lateral limits of the ore bodies were important as channelways for solutions depositing ore becomes to some degree, at least, a supposition receiving but little support from facts disclosed in mine openings.

At the time of Mr. Sales' visit our own observations were inadequate to support our present conclusions. In most areas, jasperoid, sulphides, dolomite, or calcite filled the open fissures

[4] For a more complete resumé regarding chertification the reader is referred to our discussion (Amer. Inst. Min. Eng. Tech. Pub. 446), to our reply to Dr. C. K. Leith (ECON. GEOL., Jan.–Feb., 1933), and particularly to our recent paper "Chertification in the Tri-State Mining District" (Amer. Inst. Min. Eng. Tech. Pub. 532, February, 1934).

arranged crosswise of the bedding along steep-dipping shears cutting the Boone. These minerals did not replace chert and for this reason were deposited only in openings or where there was replaceable dolomite, limestone, clayey material (locally known as selvage), or redeposited shale, which occurs within the Boone, filling subsurface openings. Minor ore bodies are found in the limestone, "selvage," and redeposited shale, which were replaced by the sulphide minerals. The original limestone was not as favorable a host rock as the gray dolomite but was more favorable than the shale.

The chertification process was completed long before the period of sulphide mineralization, as pointed out by us and by Mr. Sales There was, therefore, a host rock that consisted of beds of limestone, beds with limestone and dolomite, beds with partly chertified limestone, beds that were completely chertified, and shale-filled openings. Mineralizing sulphide solutions following a vertical or nearly vertical shear zone across these beds could form ore bodies only where there was dolomite, limestone, or shale to replace and openings to fill. The chertified beds afforded only the openings on shear planes for deposition of minerals, and in most instances these planes were tight. Where there were openings a fraction of an inch to an inch in width, some of them became lined or filled with small quartz, sphalerite, galena, dolomite, or calcite crystals, or jasperoid. Larger openings a few inches in width in many cases were completely filled with either galena or sphalerite, or both. With a host rock that could accommodate sulphide mineralization only in certain favorable beds, it is natural that the ore bodies should be conformable to these beds. We make practical use of this principle in ore finding by raising or sinking on fissures through cherty beds into favorable beds above or below the mine workings. In some mines there are as many as five favorable beds containing ore bodies arranged vertically in a shear zone and separated by unfavorable barren chertified beds. In a few mines where the shattering and shearing produce sufficient openings in the chertified beds, enough sulphide mineralization occurred to make commercial ore bodies 100 feet or more in

height. In areas of less chertification, traversed by shear zones younger than the chert, high, narrow ore bodies are common.

On page 782 Mr. Sales, in reference to Plate III of Weidman's work, which purports to show the relation of shearing or fissuring to mined ore bodies, states:

> The conclusions which might be drawn are that there is no definite fracture pattern, and that there is no order of direction or course of the shears or fissures. Furthermore, as drawn, the fissures exhibit a remarkable parallelism and commonly they begin and end within the walls of the stope opening. Marked and sudden changes in strike are shown to be very common and the inevitable conclusion is that projections of fissures on strike made beyond the point of the pick into unexplored ground are wholly unreliable and most hazardous. Study of Plate III prompts the question whether the stopes were following a series of shear planes, or the shears were drawn to fit the stopes.

Our structure map of the area differs from Weidman's. Flexing of the beds has to be considered as well as deformation by shearing and fissuring. Flexing produces curved fractures that present a bewildering arrangement to one who does not recognize it.

Shear (fissure) zones are found in a large percentage of the mines in the entire district, including all of those which Mr. Sales examined in 1927. Further observations by him would have revealed a continuous shear zone nearly one-half mile long in the Cherokee-Bendelari Mines; several of nearly equal length in the workings of the old Commerce Camp; one more than one-fourth mile long in the Adams-Mudd Mines; and numerous shorter ones in nearly every mine in the Oklahoma-Kansas field.

On page 782 he states:

> It may be assumed, I think, that some fissuring or shearing accompanied the first crumpling and folding of the Boone. According to Fowler and Lyden (Fig. 14) the Miami fissure zone is pre-Cherokee, therefore older than the igneous activity responsible for the introduction of the ores. Whether the post-Cherokee igneous activity resulted in new fissuring being imposed upon that already in existence, is also a question difficult of solution. It is well to note that there has been little or no faulting or fissuring since sulphide deposition ceased.

The Miami fissure zone is both pre- and post-Cherokee. Fig. 14 in our paper shows both these age relations. Drill-hole data from many parts of the Miami shear trough indicate that much of the movement in the deep graben-type trough structures is post-Cherokee in age, and surface exposures of the Cherokee shales and sandstones show sharp flexures into these troughs.

Mr. Sales infers that in parts of the Oklahoma-Kansas field these ore deposits are in complex areas where it is impossible to determine structural relations or the sequence of geologic events. This was our first impression, but after differentiating the respective beds we found the geologic problem to be much simpler. All of the Boone strata have retained a nearly constant thickness throughout the field; even in zones of intense brecciation or deformation there has been but little thinning of the Boone strata by solutions.

Mr. Sales devotes several additional pages to a discussion of the chertification, deformation, and mineralization in this district. Some of his discussion agrees with our observations. We definitely recognize three *important* periods of deformation, each regional in character, and can distinguish their relation to the respective periods of mineralization. They are as follows:

1. Deformation of the limestone in Mississippian time before chertification.
2. Reopening of the same general zones of adjustment, with additional deformation preceding ore deposition.
3. Further deformation of strata subsequent to the ore deposition. (Mr. Sales failed to distinguish this deformation from the earlier ones.) Nearly all of the loose, angular broken rock, so common throughout the district, was formed during this period. Some of it undoubtedly is due to collapse caused by solution of limestone beds and is distinguishable.

In the field, as a whole, there was very little dissolving away of the limestone. During the period of chertification there was much replacement of the limestone by the chert, with very little of it dissolving away to produce openings. After the period of chertification there were a few beds, such as K and M beds, that contained limestone which circulating solutions could reach and dissolve through the sheared and shattered zones and through

openings on the bedding planes. For this reason caves are local and usually confined to one or two beds; and the collapsed areas are also local and due to the solution of these same beds. The chert beds above these collapsed areas show little thinning due to solution and, except at the points of movement, are but little disturbed. None of the beds from D to S, inclusive, vary in thickness (except locally, due to solution), more than one to three feet throughout the Oklahoma-Kansas field. These conditions are confirmed by many thousand drill holes and underground observations.

Mr. Sales states that he finds himself puzzled over our statement that

Shale, which was deposited during Cherokee times, is now often found in the disturbed areas of the Boone formation in openings of all sizes and shapes and in places extending 300 feet or more below the top of the Boone. In some areas it traveled laterally for long distances from the contiguous shear zones in the Boone formation, through which it was transported downward into the ore-bearing horizons.

He comments that

In all my trips underground in the Picher-Miami district I saw but little to indicate that circulating waters had transported substantial quantities of shale to the ore zone, and I wholly disagree with Fowler's verbally stated belief that the dark color of certain bands of bed "M" are related to the Cherokee.

In discussing the brecciation of M bed, Mr. Sales mentions the presence of shale where he states that there is ". . . a mixed up jumble of shale and angular sharp-edged chert fragments . . . ," and again, in discussing our statement regarding the shale he mentions silicification of the shale to form jasperoid where he states ". . . that the lower 6 feet of the so-called "M" bed, where not soaked up with silica to form jasperoid, is black or nearly so, closely resembling highly carbonaceous shale." These last two sentences describe the shale and the silicification of the shale in M bed to form jasperoid; and the following sentence ". . . that the black coloring was pre-mineral in age is proved by the gray to black color of the so-called jasperoid," is also true concerning both the age of the shale and the age of the jasperoid-sulphide period of mineralization. Now for the source of the

shale, we quote the following sentence in which Mr. Sales recognizes deformation involving the Cherokee:

> Where solution activity was most intense, important thicknesses of the Boone were involved, resulting in jumbled breccia areas or pipes composed of chert, dolomite, limestone, etc., cutting vertically through that formation, in places reaching and involving the overlying Cherokee.

There are many fissures and openings throughout the district that are filled with shale, and many vertical and steeply dipping ones have been followed in mine workings to the Cherokee shale beds above. Obviously, during the initial deposition of the Cherokee shale it found its way into whatever openings extended downward from the old Boone land surface. However, most of the openings in the Boone were created by deformation and solution long after the deposition of the Cherokee, and were filled with shale which had caved into circulating waters and was carried and forced downward and laterally, and redeposited before, during, and after the period of sulphide mineralization. Much of the shale was replaced by silica to form jasperoid or, as stated by Mr. Sales, it was ". . . soaked up with silica." The gradual transition from jasperoid in the intensely mineralized areas to unaltered shale at the edges of these areas can be seen in many mine workings. The chert underwent no chemical change from the solutions during the jasperoid-sulphide period of mineralization. M bed contains no black shale except in the areas of disturbance. Where M bed is not chertified it consists of a very pure limestone. The chert in this bed is white to light gray, which is an indication that the limestone that was replaced was relatively pure. All of the Boone, including M bed, was originally limestone, grayish or brownish in color. The lower six feet of M bed is generally massive limestone, or limestone containing chert nodules. The chief source for the black carbonaceous shale, which is found associated with the ore bodies, is the Cherokee formation above.

Mr. Sales states that: "It is inconceivable that water could have caused a substantial lateral migration of shale." Factors other than water entered into the migration of the shale. The shale is soft and caves easily. While mining ore in beds close

to the shale, the miners have to be careful not to break through the roof into the shale, for it will cave through openings 5 to 10 feet in diameter and fill the drift. When the openings formed beneath the shale in the Boone, the circulating waters with the aid of gravity loosened the shale and helped in its caving into these openings, whence it was carried or forced into the contiguous openings between the beds. In some areas collapse of the rock mass above shale-filled openings compacted the shale and forced it into all the available space.

All the shale and dark shaly or oily material now found within the Boone occurs only in or related to zones of structural disturbance and evidently was introduced subsequent to the deposition and consolidation of this limestone.

GEORGE M. FOWLER,
JOSEPH P. LYDEN.

JOPLIN, MISSOURI,
March 13, 1935.

REVIEWS

Geology and Mineral Resources of the Hammond, Antwerp, and Lowville Quadrangles, New York. By A. F. BUDDINGTON. Pp. 251, pls. 40, figs. 18. New York State Museum Bull. 296, 1934.

The Adirondacks have long been classic ground for the study of igneous and metamorphic rocks, but the generally poor exposures, the complex geology, and the physical difficulties confronting the geologists have not, in general, permitted mapping adequate to modern structural and petrologic needs. The present report contains in the map of the Hammond quadrangle what must surely be the best piece of areal mapping yet to come out of this difficult field. The other maps are also creditable but, perhaps because of poorer exposures, are not up to the Hammond in expression.

The author's precision, so obvious in the maps, is evident throughout the report—in the many modal analyses of the igneous rocks, in the descriptive petrography of the metamorphic rocks, and in the objective discussion of the history recorded in them. The factual basis of the report is thus unusually sound and is a solid contribution, whatever the vicissitudes of geologic theory may be.

In view of these merits, it must seem ungrateful to point out omissions in a work of this type—no one man can hope to cover equally well all aspects of the geology of so complex a region. However, there will be regret that more attention was not paid to the minutiae of structure. Linear elements are marked in but few places, and the light that their systematic study might throw on the structural history, as exemplified by the work of Balk in the eastern Adirondacks, is accordingly lacking. The solution of the structural problems here must require collection of much more macroscopic and microscopic data on the vectorial features in the rocks.

The author's commendable caution in refusing to fall into the metaphysical pitfalls of stratigraphic correlation in the Grenville (and the "Laurentian" versus "Algoman" or other age of the intrusive rocks) seems to have become excessive in the sections treating of the igneous cycles, wherein the granitic and syenitic rocks are all tentatively referred to a single cycle. The evidence presented on the maps and in the text strongly points to the Croghan complex being much younger than the

Diana complex, and it seems that further progress in this region would be more stimulated by retaining the older hypothesis of at least two cycles. On the other hand, the author appears justified in his suggestion that the Alexandria and Hermon type granites probably belong to the same cycle.

The author's hesitancy to draw sweeping conclusions, despite a probably unequaled acquaintance with Adirondack problems in general, reflects a healthy reaction from the excessive theorizing that has gone on in this field. Nevertheless, his further discussion of the facts here recorded must be eagerly awaited because of his broad approach, in which are employed petrography, structure, and chemistry. His conclusions may be confidently expected to provide further working hypotheses more viable than most that have come out of the Adirondacks on the basis of less penetrating studies.

The mineral deposits of the area are of no present importance. They include: some hematite deposits found at the contact of the Potsdam and the Grenville gneisses (attributed to pre-Cambrian weathering of pyritic impregnations); galena veins, regarded as deposits from relatively cold solutions in post-Ordovician time; and pyritic and pyrrhotitic impregnations in shear zones. Nonmetallics include a little graphite, as well as considerable limestone of both Grenville and Ordovician ages, dolomite and marble of the Grenville, sandstone (Potsdam), and the customary plethora of glacial sands and gravels. The district contains many mineral localities of interest to collectors.

JAMES GILLULY.

Um das geologische Weltbild: Malleo et Mente. By DR. ERICH HAARMAN. Pp. 119, figs. 23. Ferdinand Enke, Stuttgart, 1935. Price, 5.80 RM.

The author presents a noteworthy essay, the content of which should be familiar to all speculative geologists as well as to those who are accustomed to explain observed facts by theories that have been promulgated by predecessors whom they regard as authorities. The thesis of the essay is that more progress would be made in solving geological problems if geologists would test the theories of authorities before using them in explaining observed facts. "Fehler sollen keine Galgen, sondern Wegweiser sein."

His thought is that the acceptance of error as truth will kill all progress in geological knowledge. If we study accepted theories and destroy any error that may be in them, the error itself will help us to find the correct path along our slow and laborious road to the truth. He therefore advises students of geology to prove its methods and the foundations on which it rests, and to build their future theoretical structures in accord-

ance with the results of their studies. He proceeds accordingly to follow his own advice and discusses his subject in his incisive manner under these heads:

> Only a few of the fundamental theories of Geology are surely sound.
> There is a great lack of clear and accurate physical concepts in them.
> Are mechanical laws as we know them effective in the Earth's crust?
> The necessity of the knowledge of Man's "personal equation" in estimating the value of generally accepted theories.

His most comprehensive conclusions are the two following: (1) the Earth's crust is anisotropic and therefore does not respond to simple physical laws as developed from experimentation under assumed simple conditions; and (2) criticism is a positive method of investigation, since until we discover errors in our accepted conclusions, we cannot proceed farther toward the truth.

The essay is well worth study by all research and teaching geologists.

W. S. BAYLEY.

Life History of the Sudbury Nickel Irruptive: I. Petrogenesis. By W. H. COLLINS. Trans. Roy Soc. Canada, Sec. 4, Ser. 3, vol. 28, pp. 123–177, 1934.

This is the first of a projected series of papers on the Sudbury irruptive and represents an outstanding contribution of new data and interpretation for one of the classic examples of a large differentiated sheet-like mass of igneous rock. The report is based on field work by Dr. Collins and his assistants during the period 1928–1932, in the course of which the whole nickel irruptive was remapped and a transition zone between the norite and micropegmatite was defined and mapped.

New data supplementary to those previously available are presented and utilized in a discussion of the "transition zone," the "offset intrusions," and the specific gravity variations across the irruptive. It is found that the transition zone occurs entirely around the elliptical outcrop of the basin, is between 250 and 800 feet wide, and shows a regular gradation from norite to micropegmatite. Curves are given for the chemical and mineralogical variations across two sections of the transition zone.

The mechanics of the differentiation are discussed. The hypothesis of assimilation as a major factor is discarded, essentially because of lack of evidence for assimilation at the base as well as at the top and because of the uniformity of the micropegmatite. The idea of two successive intrusions with the formation of a hybrid zone at the contact is not accepted for lack of critical evidence in favor of it, and improbable dynamics. Crystal sorting and separation of liquid from crystals is con-

sidered inapplicable, except on a small scale, because of certain inconsistencies with what it is deduced should be expected on this hypothesis, and because it is inadequate. Maxima on the specific gravity profiles in the vicinity of the transition zone are interpreted by Collins as due for the most part to a concentration there of ilmenitic magnetite. This he considers to be opposed to the principle of differentiation through fractional crystallization since, because of its high specific gravity, it should have sunk. The author concludes that there is only one tenable conclusion:—the original magma separated in the liquid state into norite and micropegmatite magmas. He calculates the average composition of the irruptive, on the assumption that the present exposed surface is the bevelled edge of a symmetrical three-layered tabular mass, and is in all likelihood a good index of the volumes of the component layers. This gives a composition (63.14 per cent. SiO_2), approximating a member of the transition zone. From this, and from the chilled textures, it is deduced that the offset intrusions which are more basic (58–59 per cent. SiO_2) could neither have been a "mush" made basic through settled crystals nor a squeezed-out residual (necessarily more salic) liquid, and hence must have been one liquid segregate from the original magma, while the micropegmatite magma was the other.

There are a few additional points which the reviewer would have liked to see discussed by Dr. Collins. For example, the question as to whether ilmenitic magnetite (and apatite) may have accumulated in large part in the liquid phase during differentiation up to a certain composition, so that its period of maximum precipitation did not occur until an intermediate stage of differentiation; an hypothesis that the offset intrusions might represent more or less the original magma (much of the lower part of the northern border of the sheet shows a similar chemical composition) and that therefore there must have been some differential movement of the micropegmatite magma, so that the present surface exposure does not give a good index of the volume of the component layers. Are there any chilled dikes in the country rock corresponding in composition to the primary magma postulated by Dr. Collins?

The final conclusion that both norite and micropegmatite differentiated as liquids from a common magma is not in accord with prevailing opinion; but, as several geologists have pointed out, there is at present no really positive experimental proof that granitic magmas relatively rich in water cannot be immiscible with basic types, although the present data are in general unfavorable to it.

The paper gives a most excellent presentation of a wealth of data available for the discussion of the petrogenesis of the sheet; it deserves reading by all interested in this subject.

A. F. Buddington.

Laboratory Manual for General Geology. By M. H. SECRIST. Pp. 284, illus. Macmillan Co., New York, 1935. Price, $1.75.

Another guide to laboratory work for beginning students in general geology, which differs from most of those heretofore offered. In effect, it is more general than most, as will be seen from the subject headings:—minerals, rocks, topographic maps, earth history, geologic maps, block diagrams, paleontology, the plant kingdom, the animal kingdom and bibliography. Structural geology as a separate division is not discussed, "because in the exercises on topographic maps and profile sections and on geologic maps and geologic sections, the student is dealing largely with structures." The book is well put up, with interleaved blank and ruled pages and sheets of profile paper, and it is profusely illustrated with significant figures. The text is carefully written; some sections, however, will require rather more explanation on the part of the instructor than is usually given to students using guides.

Tin. Issued by Pardners Mines Corporation, New York, 1935. Private distribution. Pp. 70, tables 24, figs. 7.

This represents an extensive study of tin made by Pardners Mines engineers and placed in book form for permanent record. The subjects treated are: The metal and its uses, world distribution, production by continents and countries, consumption, recovery of secondary tin, world stocks and reserves, smelting, and prices. Many charts and tables give voluminous statistics. It is a concise, well rounded study, and of value to all interested in mineral economics.

BOOKS RECEIVED

DAVID GALLAGHER.

The Architectural, Structural and Monumental Stones of Minnesota. G. A. THIEL AND C. E. DUTTON. Pp. 16, figs. 78, pls. 12. Minnesota Geol. Survey Bull. 25, Minneapolis, 1935. Rocks used for structural and ornamental purposes, methods of working them, their location and uses; abundantly illustrated with figures and color plates.

Min. da Agric., (Brazil) Dept. Nac. da Prod. Min., Serv. de Fomento da Prod. Min., Rio de Janeiro. Bol. 1, 1934. Notas Preliminares sobre Algumas Jazidas de Minerio de Ouro do Estado de Minas Geraes. D. GUIMARAES AND V. OPPENHEIM. Pp. 27, figs. 16, maps 4. Brief notes on gold occurrences. **Bol. 3. Depositos Diamantiferos no Norte do Estado de Minas Geraes (Brazil).** L. J. DE MORAES. Pp. 77, figs. 30. Geology and occurrence of alluvial diamonds in northern Minas Geraes, with chapter by V. OPPENHEIM on diamond occurrence along the Abaete River. **Bol. 5. Rochas Gondwanicas e Geologia do Petroleo do Brasil Meridional.** V. OPPENHEIM. Pp. 129, figs. 61, maps 2. Petroleum occurrences, distribution, structure and detailed stratigraphy of Central Brazil. **Bol. 6. Chumbo e Prata no Estado de Sao Paulo.** O. H. LEONARDOS. Pp. 47, illus. 16, map. Brief geological descriptions of lead and silver deposits of Sao Paulo.

Mineral Industry of New Jersey for 1933. M. E. JOHNSON. Pp. 20, pls. 4. N. J. Dept. Conserv. and Devel. Bull. 42, 1935. Statistical, industrial.

Reconnaissance of the Northern Koyukuk Valley, Alaska. R. MARSHALL. Pp. 9, sketch map. U. S. Geol. Surv. Bull. 844–E. Washington, 1934. 5 cts. Geography only.

Girdwood District, Alaska. C. F. PARK, JR. Pp. 44, figs. 8, map in color. U. S. Geol. Surv. Bull. 849–G. Washington, 1933. 25 cts. General geology; description of mines; arsenopyrite-gold-quartz veins.

Book Cliffs Coal Field, Garfield and Mesa Counties, Colorado. C. E. ERDMANN. Pp. 150, pls. 21, figs. 7, map in color. U. S. Geol. Surv. Bull. 851. Washington, 1934. 35 cts. Area of 500 square miles containing four zones of Upper Cretaceous bituminous coal; reserves given; local details.

Curry District, Alaska. R. TUCK. Pp. 42, pls. 4, figs. 2. U. S. Geol. Surv. Bull. 857–C. Washington, 1934. 10 cts. General geology.

Notes on the Geology of the Alaska Peninsula and Aleutian Islands. S. R. CAPPS. Pp. 12, pls. 1. U. S. Geol. Surv. Bull. 857–D. Washington, 1934. 5 cts. Reconnaissance.

Core Drilling for Coal in the Moose Creek Area, Alaska. G. A. WARING. Pp. 12, pls. 4, figs. 1. U. S. Geol. Surv. Bull. 857–E. Washington, 1934. 10 cts. Economically unfavorable.

Paleozoic Formations of the Mosquito Range, Colorado. J. H. JOHNSON. Pp. 28, pls. 7, figs. 1. U. S. Geol. Surv. Prof. Paper 185–B. Washington, 1934. 10 cts. Stratigraphic.

Geology and Mineral Resources of the Hammond, Antwerp, and Lowville Quadrangles (New York). A. F. BUDDINGTON AND R. RUEDEMANN. Pp. 251, figs. 54, 4 maps in color. $2.50. N. Y. State Mus. Bull. 296. Albany, 1934. Detailed and extensive geological report of much interest.

Geology of the Potsdam Quadrangle (New York). J. C. REED. Pp. 98, figs. 60, 2 maps in color. 75 cts. N. Y. State Mus. Bull. 297. Albany 1934. Detailed study.

Results of Sampling Newfoundland Gold Prospects. A. K. SNELGROVE AND C. K. HOWSE. Pp. 15, map. Newfoundland Dept. Natural Resources, Inform. Circ. 1. St. John's 1934. Statistical.

Quebec Bureau of Mines, Annual Report, 1933, Pt. C. Pp. 114, pls. 9, figs. 21, 2 maps in color. Quebec, 1934. Contains: McWatters Mine Gold Belt, East-Rouyn and Joannès, J. E. HAWLEY; Beattie-Galatea mines map area, Duparquet Township, J. J. O'NEILL.

Artesian Water in Somervell County, Texas. A. G. FIEDLER. Pp. 86, pls. 7, figs. 5. U. S. Geol. Surv. W. S. P. 660. Washington, 1934. 15 cts.

Contributions to the Study of Coal. E. T. BENSON AND G. H. CADY. Pp. 41, figs. 13. Illinois Geol. Surv., Rpt. of Inves. 35. Urbana, 1935. Influence of Structural Irregularities upon the Chemical Character of No. 6 Coal in Franklin and Williamson Counties; distribution of sulfur in Illinois coals and its geological implications.

Geology and Fuel Resources, Southern Part of San Juan Basin, New Mexico. Pt. 1. The coal field from Gallup eastward toward Mount Taylor. J. D. SEARS. Pp. 29, pls. 17, map in color. U. S. Geol. Surv. Bull. 860–A. Washington, 1934. 35 cts.

Mineral Industry of Alaska in 1933. P. S. SMITH. Pp. 94, figs. 3. U. S. Geol. Surv. Bull. 864–A. Washington, 1934. 10 cts. Statistics; bibliography of Alaskan geology.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SCIENTIFIC NOTES AND NEWS

John Campbell Merriam, president of the Carnegie Institution at Washington, and Raymond C. Moore, State Geologist of Kansas, were appointed by the U. S. Government as the official delegates to the centenary celebration of the Geological Survey of Great Britain, which was held in London on July 3–5.

E. S. Moore, of the Canadian Geological Survey, is in charge of a geological surveying party at Ramore.

W. E. Wrather, of Houston, Texas, was a recent visitor in New York City in connection with the financial affairs of the Geological Society of America.

L. C. Graton, of Harvard University, has left the United States for a trip to Peru.

D. H. McLaughlin, of Harvard University, has returned from an extended professional trip to Australia via South Africa and London.

W. T. Thom, Jr., has been promoted from associate professor of geology to a full professorship at Princeton University.

W. O. Hotchkiss, for the last ten years president of the Michigan College of Mining and Technology, has been elected president of Rensselaer Polytechnic Institute, Troy, N. Y.

J. B. Stone has left Bendigo temporarily to examine mineral properties in Fiji.

E. N. Cameron, of Columbia University, has been awarded the Emmons Memorial Fellowship for the year 1935–36.

Desmond F. Kidd, of the Geological Survey of Canada, has resigned his position and will engage in private geological work in British Columbia and the Mackenzie District, N. W. T., with headquarters in Vancouver.

The San Antonio Section of the American Association of Petroleum Geologists will hold its seventh annual meeting at Mexico City, October 16–17.

G. S. Scott is consulting geologists for Paymaster Consolidated Mines, Ltd., South Porcupine, Ont.

F. E. Calkins has been examining several properties in Yavapai County, Ariz.

H. E. McKinstry is now at 120 Wall St., New York, with Case, Pomeroy & Co.

Thorold F. Field, a director of Roan Antelope Copper Mines, Ltd., has returned from Northern Rhodesia via London.

Donald K. Mackay has resigned his position with the International Nickel Co., New York City, to resume geological work.

C. P. Browning, of Britannia Mining & Smelting Co., Ltd., is chairman of the British Columbia division of the Canadian Institute of Mining and Metallurgy for 1935.

Charles Camsell, deputy minister of mines of Canada, received the title of Companion of the Order of St. Michael and St. George in the distribution of honors on the birthday of King George.

Ernest F. Burchard has been granted the honorary degree of Doctor of Science by the University of Alabama.

Sydney Paige, who has served for two years as advisor on mineral resources for the Department of Economy of the Turkish Government, is now resuming consulting practice in Washington, D. C.

M. C. Lake, of Duluth, Minn., is president of the Dairy Farm Gold Corporation, Lincoln, California, succeeding Orrin P. Peterson.

B. D. Stewart, of the U. S. Geological Survey, has been appointed Commissioner of Mines for Alaska, under a recent act of the Territorial Legislature establishing a Department of Mines.

G. C. Gester is now chief geologist for Gold Gravel Products, Inc., which is washing about 3000 cu. yds. of gravel a day at Wallace, Calif.

The National Research Council has made the following awards in geology and geography:—Charles Deiss (University of Montana): Stratigraphic and Paleontologic Studies of the Cambrian of Montana and Wyoming; D. M. Fraser (Lehigh): Petrogenesis of the Crystalline Rocks in Eastern Pennsylvania; E. C. Jacobs (Vermont): Installation of a Seismograph at the University of Vermont; K. C. McMurry (Michigan): Development of Methods for Utilizing Aerial Photography in Land Inventory and Classification; O. B. Muench (New Mexico Normal): Determination of Age of Monazite and Thucholite from Glorieta, New Mexico; F. J. Pettijohn (Chicago): Analysis and Correlation of Areal Mapping in the Lake Superior Pre-Cabrian; G. Rittenhouse (Minnesota): Geology of a Portion of the Savant Lake Area, Ontario; H. W. Scott (Montana): Microfauna of the Carboniferous of Montana; W. H. Twenhofel and R. R. Shrock (Wisconsin): Field and Laboratory Studies of the Silurian of Newfoundland. Applications to the Committee on Grants-in-Aid for the next meeting, in March, 1936, should be sent to Dr. Clarence J. West, Secretary, before February 15, 1936.

Edward Salisbury Dana, author of the Textbook of Mineralogy and for many years editor of the American Journal of Science, died at his home in New Haven, Conn., on June 23, aged 86.

Charles H. Clapp, president of Montana University and former Assistant State Geologist of North Dakota, died recently at Missoula, Montana, aged 51.